Elekta Neuromag

Elekta Neuromag® System Hardware

User's Manual

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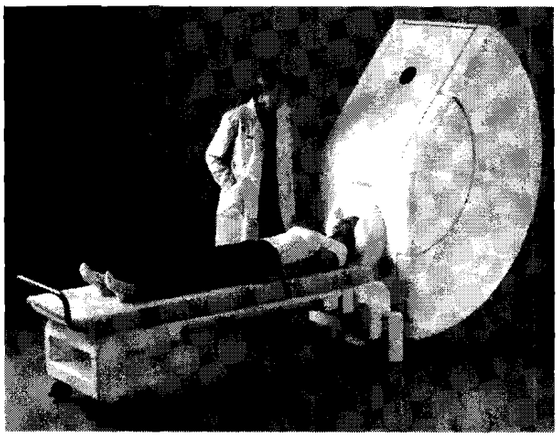

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List of symbols

The following symbols are used in the system and in the manuals. Familiarize yourself with each symbol and its meaning before operating this system.

Caution, consult accompanying documents. Parts of the system are marked with this symbol when it is necessary for the user to refer to important operating and maintenance instructions given in the manuals accompanying the system. In the manuals, it also calls attention to specific instructions. These instructions may contain procedures, practices, conditions or the like which must be correctly performed or adhered to in order to ensure safe operation and to avoid damage to the patient, operator, or the system.

Consult instructions for use. Parts of the system are marked with this symbol when it is necessary for the user to refer to important operating and maintenance instructions given in the manuals accompanying the system. In the manuals, it also calls attention to specific instructions. These instructions may contain procedures, practices, conditions or the like which must be correctly performed or adhered to in order to ensure correct operation and/or increased safety and to avoid damage to the system.

Type BF (body floating) equipment symbol. The applied parts (parts in direct contact with the person being investigated with the system) and the type plate are marked with this symbol to indicate that they fulfill the leakage current requirements of the safety standard IEC 60601-1).

Alternating current (power line) symbol.

On (power line) symbol.

Off (power line) symbol.

Protective ground (earth) terminal symbol. Used to identify terminals which are intended for connection to an external protective conductor for protection against electrical shock in case of a fault, or to the terminal of a protective ground (earth) electrode.

Static electricity symbol. The parts of the system marked with this symbol indicate the presence of components susceptible to static electricity and require the use of special static-electricity preventing techniques. See *Elekta Neuromag System Hardware: User's Manual.*

Magnetic objects and devices symbol. The use of these symbols in the vicinity of the probe unit indicate that magnetic objects or devices may cause disturbances in the operation of the system; they should therefore be avoided.

Non-ionizing radiation, RF transmitter. Marking on equipment or equipment parts that include RF transmitters or that intentionally apply RF electromagnetic energy.

Separate collection of waste electrical and electronics equipment (WEEE) necessary (European Union directive 2002/96/EC on WEEE)

Date of manufacture: year (four digits) followed by month

1. Overview of the system

1.1. Intended use

The Elekta Neuromag® non-invasively measures the magnetoencephalographic (MEG) and electroencephalographic (EEG) signals produced by electrically active tissue of the brain. These signals are recorded by a computerized data acquisition system, displayed, and may then be interpreted by trained physicians to help localize these active areas. The locations may then be correlated with anatomical information of the brain. MEG is routinely used to identify the locations of visual, auditory, somatosensory, and motor cortices in the brain when used in conjunction with evoked response averaging devices. MEG is also used to non-invasively locate regions of epileptic activity within the brain. The localization information provided by MEG may be used, in conjunction with other diagnostic data, in neurosurgical planning.

1.2. General information

Elekta Neuromag® allows simultaneous measurement of 306 MEG and 64 (optionally 128) EEG signals over the whole head. Activity of several sources all over the cortex can thus be monitored.

Elekta Neuromag® MEG channels are based on 306 superconducting thin-film sensors inside a cryogenic Dewar vessel. The gantry, which supports the Dewar, the patient bed, and the patient chair are operated inside a magnetically shielded room. MEG electronics unit outside the magnetically shielded room reads out the sensor outputs through the filter unit, digitizes the signals, and controls the operation of the sensors. A data acquisition system collects and routes the data to the main computer system, as well as controls the electronics and data acquisition.

The EEG subsystem comprises an interface for electrodes, a computer-controlled preamplifier unit, an isolation amplifier, a feedthrough filter, and a data acquisition unit. The electrode interface and preamplifier unit are built in the MEG probe unit gantry inside a magnetically shielded room. The rest of the electronics resides outside the magnetically shielded room. The device is an integral, permanently built-in part of the Elekta Neuromag® MEG system designed to be used in conjunction with MEG measurements, either simultaneously or using EEG channels only. It cannot be used as a stand-alone unit outside of the magnetically shielded room.

A head position indicator (HPI) system and a three-dimensional digitizer are also included in the system to determine the position of the head with respect to the sensor array.

The system includes a UNIX workstation for performing and controlling measurements and for on-line processing of data. Typically, another UNIX workstation is also included for off-line analysis of data. The software includes programs for data acquisition and electronics control, data display, source modeling, signal processing, magnetic resonance image (MRI) intergration, visualization of combined structural and functional data, and reporting tools.

1.3. Main system components

The MEG system typically comprises the following parts:

- Probe unit with 306-channel helmet-shaped dc SQUID (Superconducting Quantum Interference Device) sensor array inside a cryogenic Dewar
- Gantry, patient bed, and patient chair
- Filter unit to prevent radio-frequency (RF) interference to the probe unit from the environment and from digital electronics
- Electronics for operating the sensor elements
- RF-shielded cabinet for electronics
- Stimulus delivery interface for auditory stimuli
- Trigger line interface (digital)
- RF-shielded cabinet for optional stimulators with appropriate feedthroughs for signal cables and power line
- Data acquisition system with real-time computers
- Two UNIX workstations (for acquisition and analysis)
- Isolation transformers for main electronics and stimulus cabinets
- Head-position indicator system with marker coils and drive electronics
- Audio electronics with patient earphones and microphone
- Three-dimensional digitizer, non-magnetic goggles, and a digitizting chair
- Electronics to measure the liquid Helium level, comprising a probe, control electronics, and a local display
- Phantom for calibration and performance verification
- Transfer siphon for refills of liquid Helium into the probe unit
- Cryogenic Accessory Kit

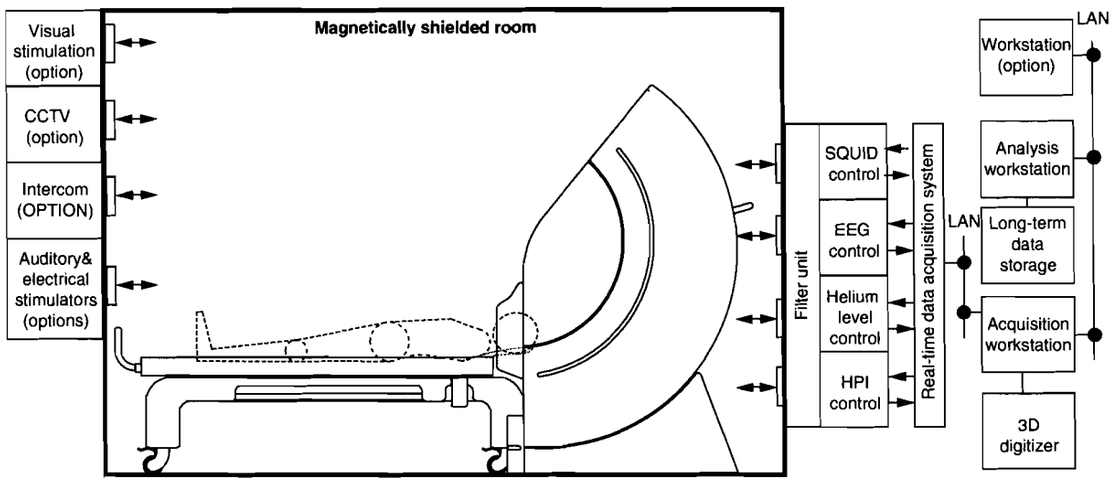


Figure 1.1. Elekta Neuromag® system block diagram

- Magnetically shielded room (provided by third party vendor)
- Helium exhaust system for venting the Dewar outside of the shielded room including an emergency vent line

The standard EEG subsystem comprises

- 64-channel electrode interface for connection of electrode caps, headboxes, and/or four bipolar (also referred as differential) single electrode pairs, reference electrode, and ground electrode
- 60-channel unipolar (also referred as single-ended) electrode cap
- 32-channel unipolar electrode headbox for single electrodes
- 64-channel preamplifier unit with 60 unipolar and 4 bipolar channels, buffered reference channel, and current-limited isolated ground electrode driver
- 64-channel optoisolator/filter built in the MEG feedthrough unit
- 64-channel data acquisition unit
- isolated power supply for the preamplifiers and for the preamplifier side of the optoisolator, built in the MEG feedthrough filter unit
- Control/nonisolated power feedthrough filter built in the MEG feedthrough filter unit (non-isolated power supplied by the MEG front end power supply)

A range of options is also available, see *Elekta Neuromag® System Hardware Technical Manual*

The main system components are summarized in Figs. 1.1–1.3. An example layout of the components is sketched in Fig. 1.4.

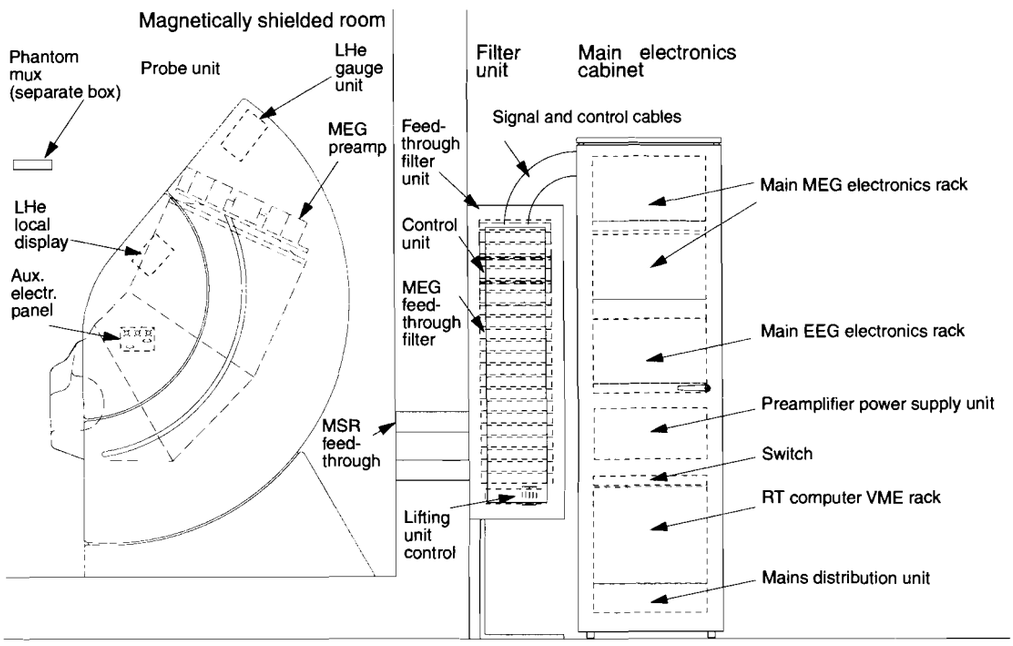


Figure 1.2. MEG electronics components

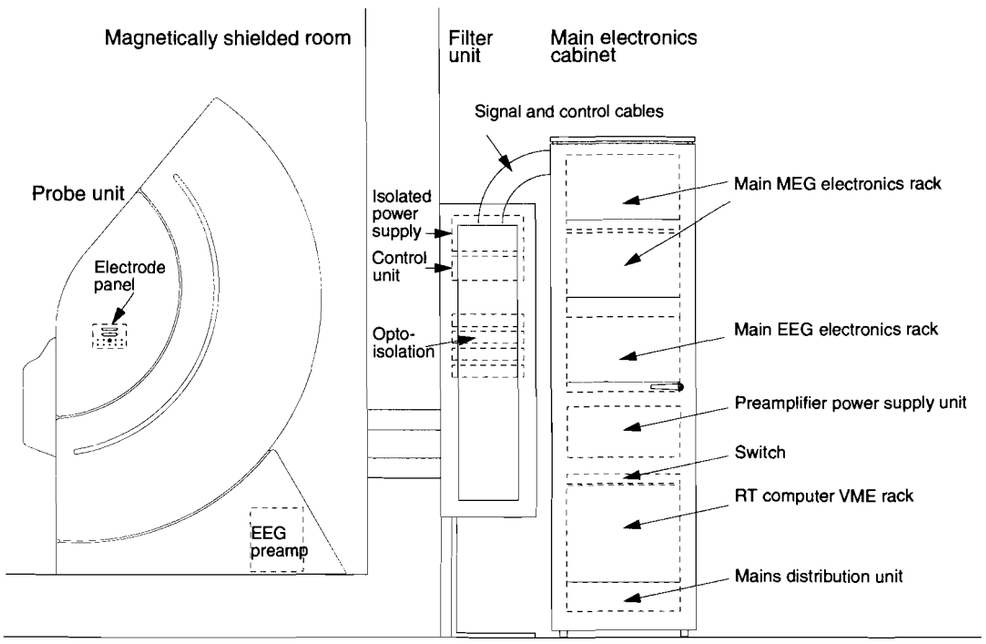


Figure 1.3. EEG electronics components

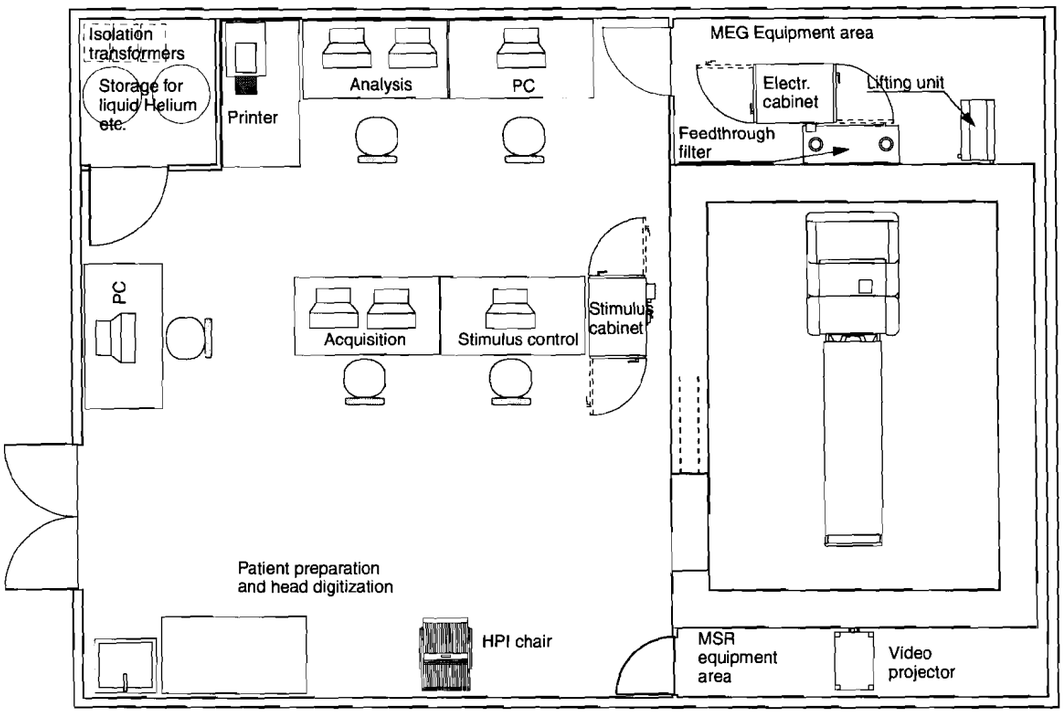


Figure 1.4. A typical schematic layout of a MEG system site. Note: the exact composition and layout of the system is site-dependent.

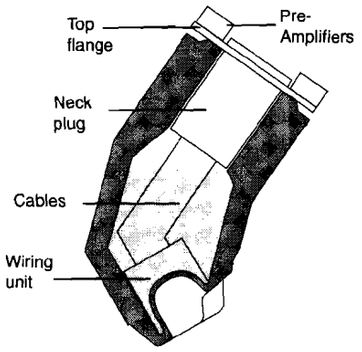


Figure 1.5. Construction of the probe insert.

1.4. The probe unit

The Elekta Neuromag® probe construction is shown schematically in Fig. 1.5. The 306 sensors measure the magnetic field distribution around the head and convert it to 306 electrical signals. The sensors are immersed in liquid Helium to keep their temperature stable at 4.2 K. At this temperature the sensors are superconducting. The 306-channel cryogenic insert contains 306 SQUID sensors positioned in a helmet-shaped array

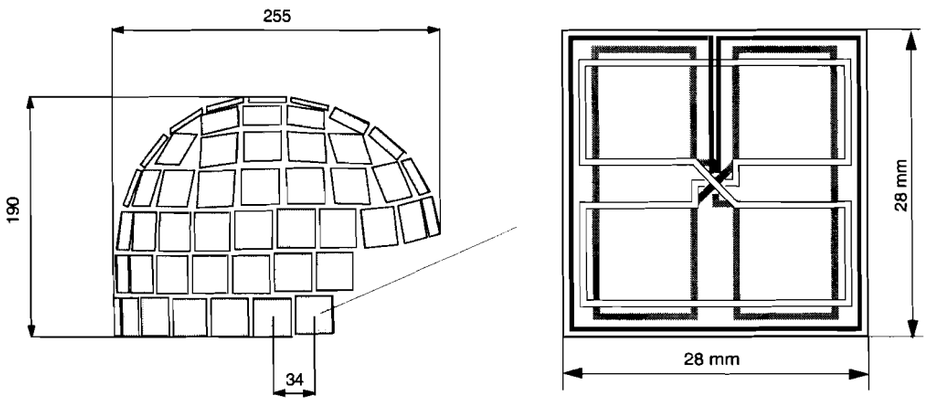


Figure 1.6. (left) Detector array, side view. Average distance between sensor elements : 34,6 mm. (right) Triple sensor detector unit.

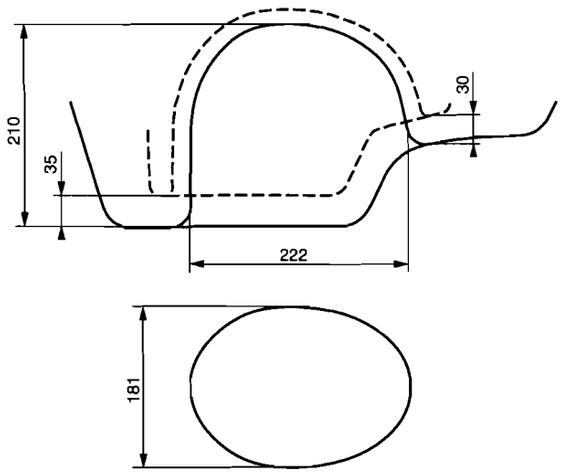


Figure 1.7. Main dimensions [mm] of the helmet-shaped lower end of the Dewar. The size of the helmet complies with the EN960:1994 standard.

and the necessary support structures and cabling. The sensor insert is inside the cryogenic Dewar.

The 306 sensors comprise 102 magnetometers that measure the B_z component which is perpendicular to the surface of the detector of the field, 102 planar gradiometers measuring the gradient $\partial B_z/\partial x$, and 102 planar gradiometers measuring $\partial B_z/\partial y$-component of the gradient. The sensors are arranged in triple sensor elements each comprising two orthogonal planar gradiometers and one magnetomer in the same plane as the planar gradiometers. For geometrical details, see Fig. 1.6.

The helmet-shaped cryogenic Dewar is a vacuum-insulated vessel to keep the liquid Helium necessary for cooling the SQUID sensors to 4.2 K. It is a double-wall structure with vacuum gap and additional thermal radiation shielding in between. The neck plug of the probe unit also provides thermal insulation. The main dimensions of the helmet are shown in Fig. 1.7.

1.5. Channel layout

Layout of MEG channels is shown in Fig. 1.8.a. The naming of individual channels is based on a hierarchical system, see Fig. 1.8.b. Each channel is identified with a 4 digit number, 'xxyz'. The two most significant digits in a channel number, e.g. '01yz', define a group of neighboring sensor elements.

The first group, '01yz', is on the frontal left edge of the array; the last group, '26yz', is on the right edge of the array.

The third digit specifies an individual sensor in a group. Typically four sensors belong into a group. E.g, 'xx2z' is the second sensor in a group.

The least significant digit is used to distinguish between three orthogonal channels of a single sensor element. Value '1' is always used for magnetometer channels. Values '2' and '3' are used for the planar gradiometers. E.g., 'xxy3' is a planar gradiometer channel of a sensor element.

NOTE: The value '2' may refer to the derivative along either latitude or longitude depending on the location of the sensor. Same applies to value '3'. For details of the naming convention, see Fig. 1.8.b.

Locations of the various sensor groups are illustrated in Fig. 1.9.a, 1.9.b, and 1.9.c.

1.6. Gantry, bed, and chair

Gantry, bed, and chair comprise a system to position the head of the subject/patient in the sensor array inside the Dewar. The gantry is used either with the bed or with the chair, depending whether measurements are made in supine or seated position. The gantry allows positioning of the Dewar in either supine or upright position (see Fig. 1.10.a and 1.10.b). The movement between the two measurement positions is motor-driven. The patient bed provides a comfortable supine measurement position. The chair provides seated measurement position which is the de-facto standard in cognitive studies. For details of the construction and usage, see Chapter 5.1.

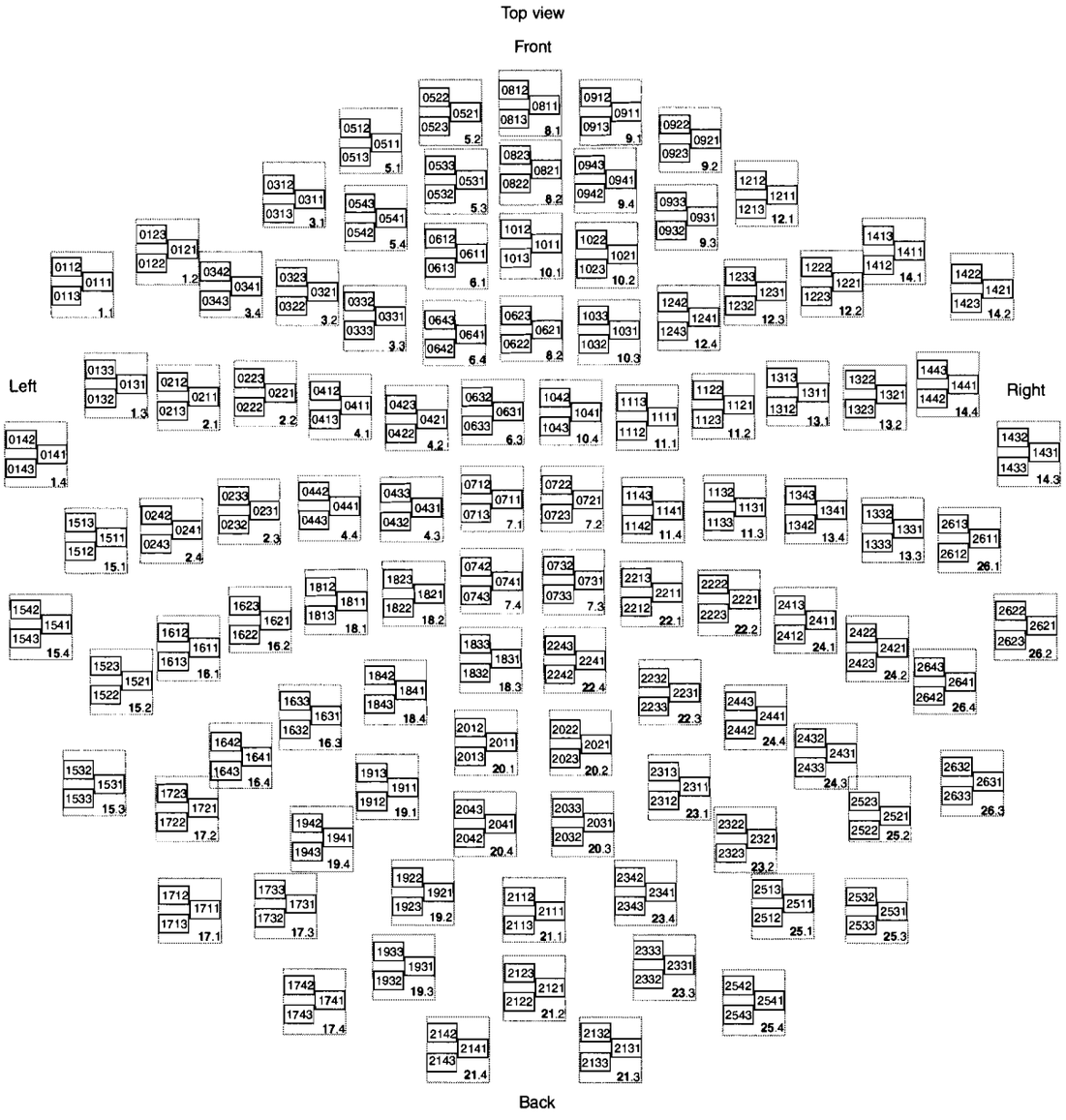


Figure 1.8.a. Layout of the sensor elements. The helmet shaped sensor array is flattened into a plane. For naming convention and gradient direction, see Fig. 1.8.b.

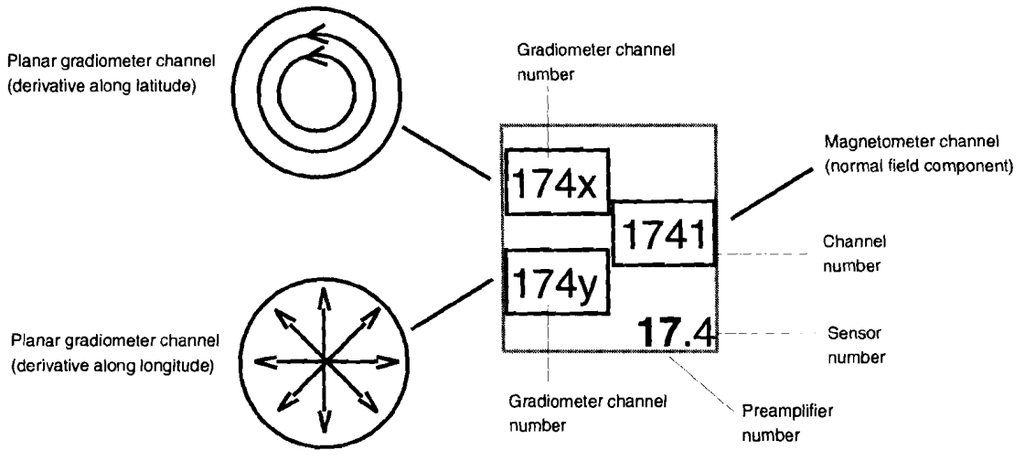


Figure 1.8.b. Naming convention. Depending on location, x=2 and y=3 or vice versa, refer to Fig. 1.8.a.

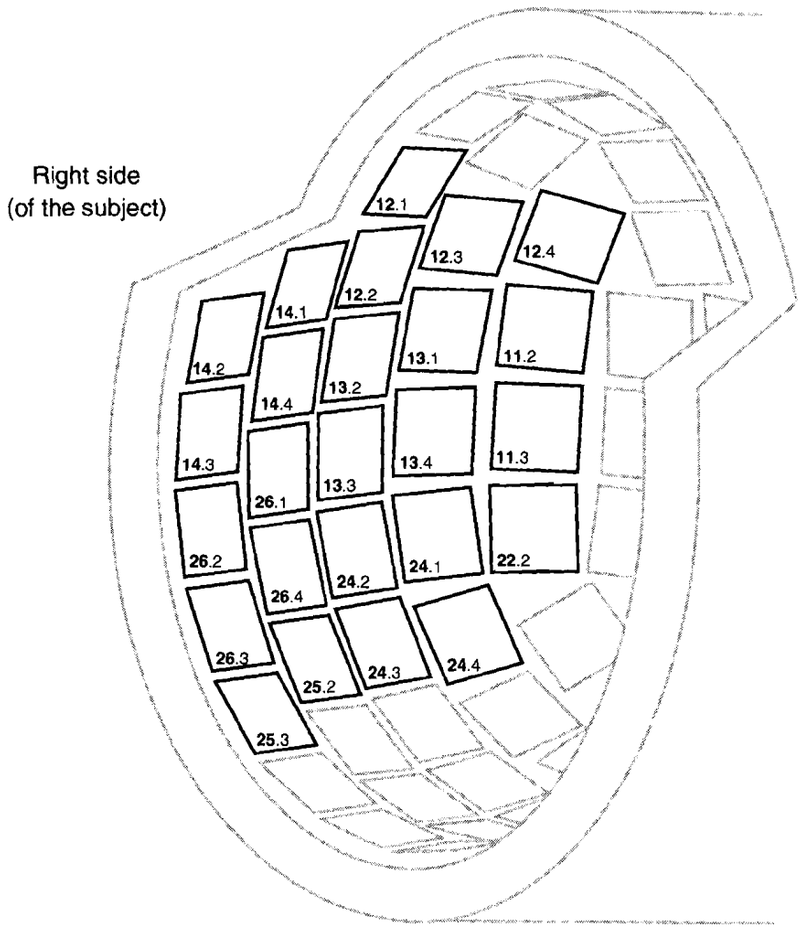


Figure 1.9.a. Naming of sensor elements

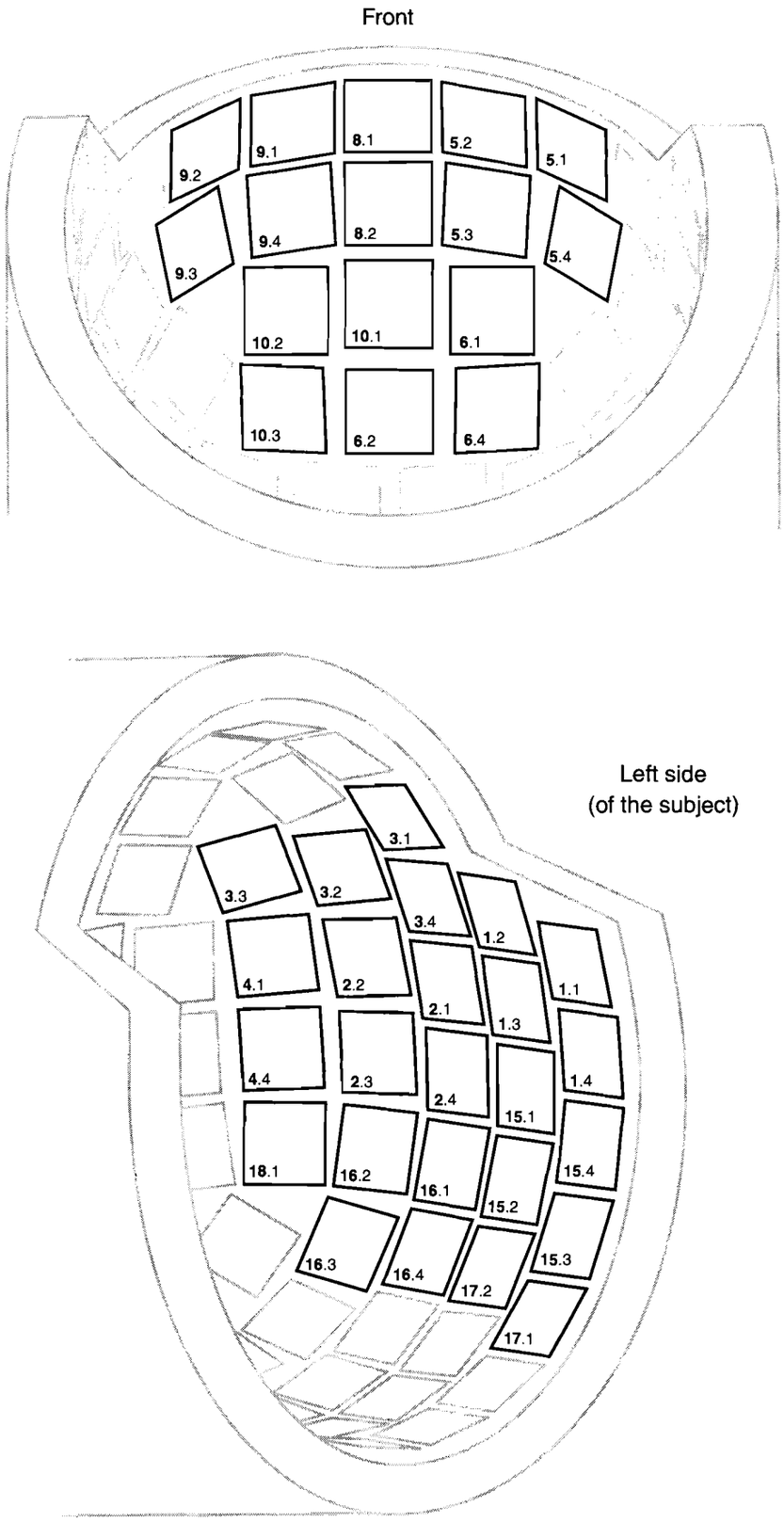


Figure 1.9.b. Naming of sensor elements

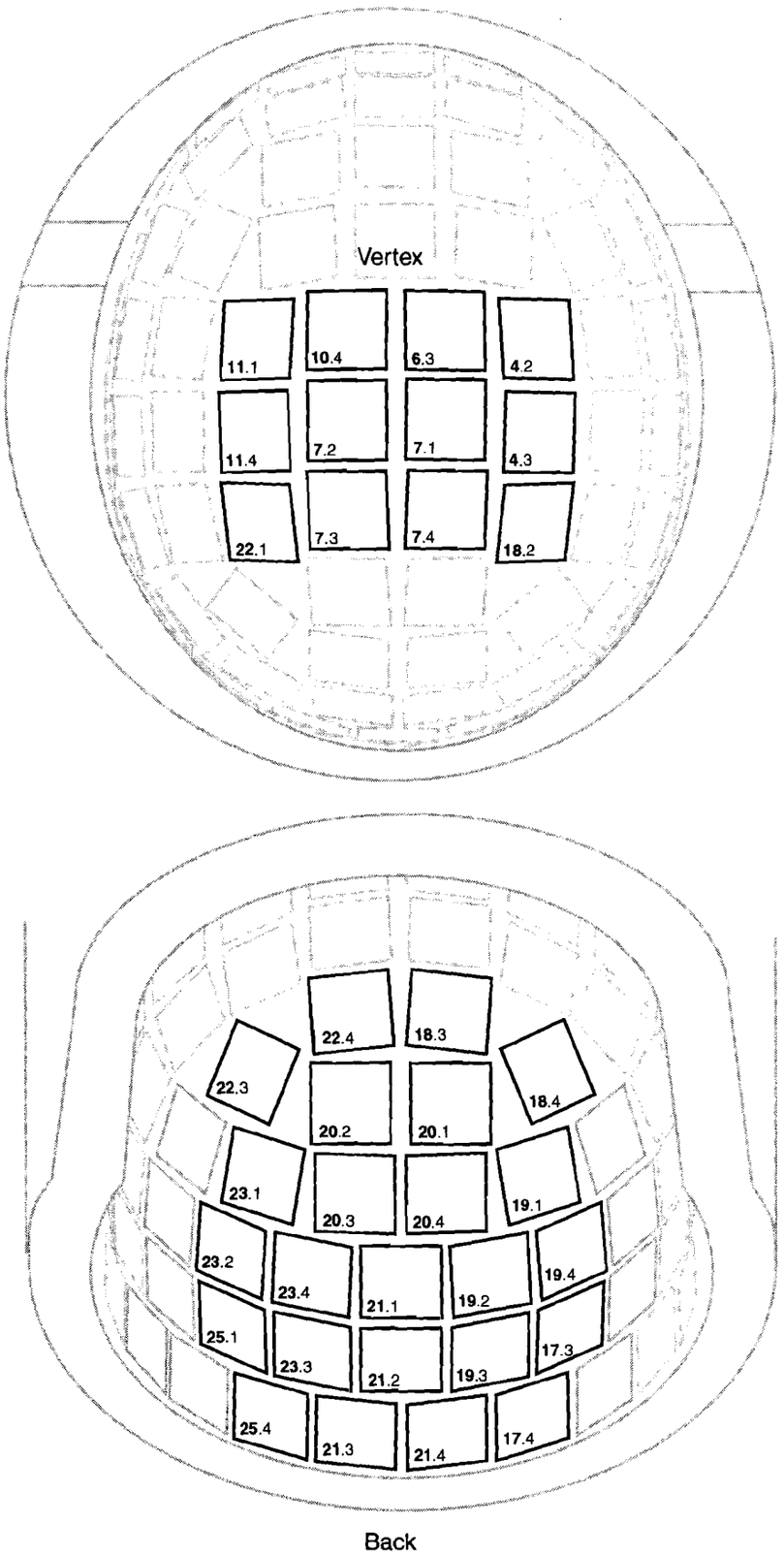


Figure 1.9.c. Naming of sensor elements

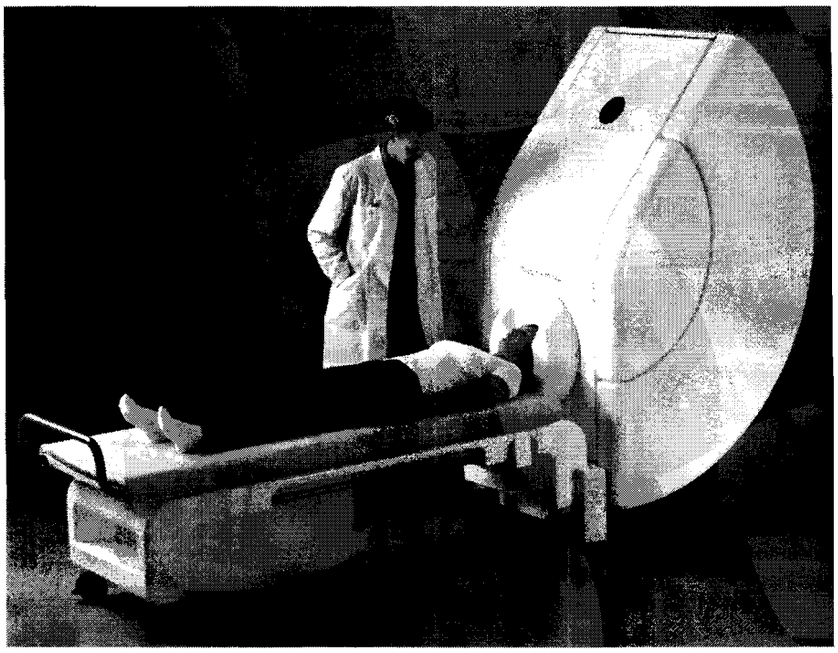


Figure 1.10.a. Supine measurement position

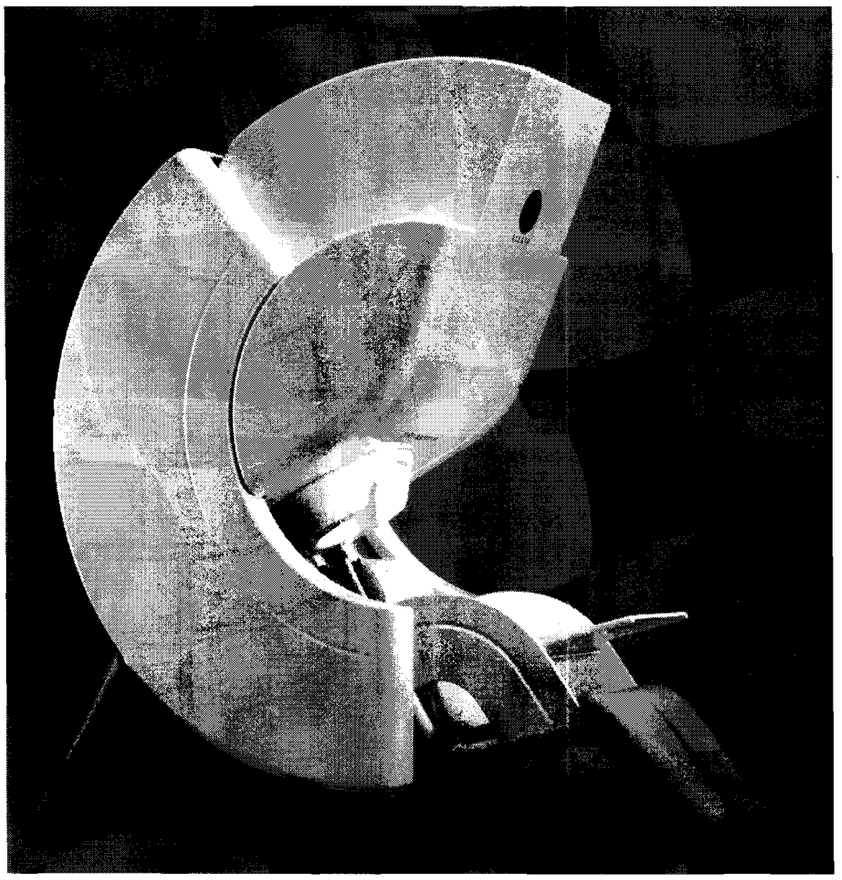


Figure 1.10.b. Upright measurement position

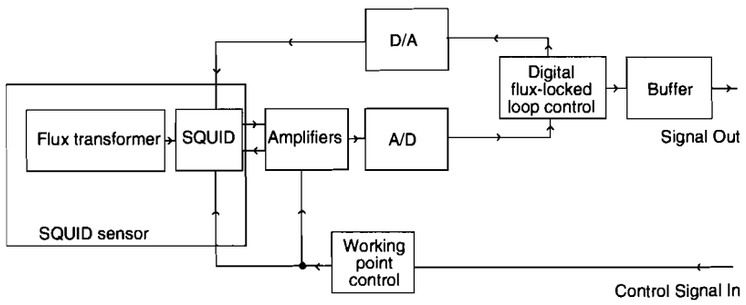


Figure 1.11. Block diagram of the SQUID electronics.

1.7. SQUID electronics

The SQUID electronics unit is used for reading out and amplifying the electrical signals from the SQUIDs. The electronics boards include preamplifiers for SQUID readout inside the probe unit, and main boards containing analog-todigital (A/D) converters, digital-to-analog (D/A) converters, and a digital signal processor for feedback loop, as well as adjustable digital anti-aliasing low-pass and high-pass filters (see Fig. 1.11). The main boards reside inside the main electronics cabinet. The boards are connected to the real-time data acquisition computers for control and for data forwarding.

Radio frequency interference shielding of the SQUID electronics is provided using the filter unit which is an appropriate cabinet outside the magnetically shielded room with feedthrough filters for all cables and isolation of power lines. The signal cables between the preamplifier boards on the top plate of the Dewar and the filter unit go through two feedthrough tubes of the shielded room.

The data acquisition system includes a dedicated optic link from the real-time data acquisition computer for controlling the preamplifiers.

Fore block and schematic diagrams of the electronics refer to *Elekta Neuromag® System Hardware Technical Manual.*

1.8. EEG electrode interface

The electrode interface is located in the gantry side panel. To access it raise the side panel cover until it locks. The interface panel is shown in Figs. 1.12. and 1.13. On the panel, there are two 37-pin male connectors (32 channels each) for connecting the electrode cap or electrode headbox. Channels 1–60 are unipolar (single-ended) and accessed through the 37-pin connectors only. Channels 61–64 are bipolar (differential). For convenience, they are also connected in parallel with the second D37 connector to the eight sockets EEG61+ ... EEG64– on the panel. Separate sockets are provided for the reference (REF) and ground (GND)

Fig. 1.12. The electrode interface panel is under the gantry side cover.

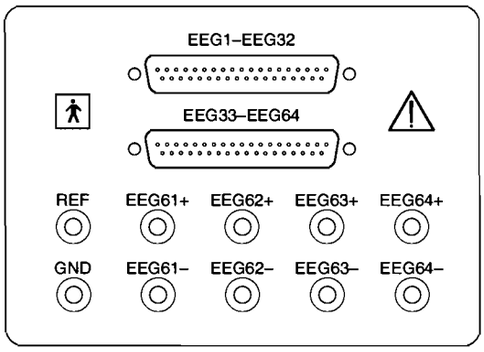


Fig. 1.13. The electrode interface panel. The connectors marked "EEG1–32" and "EEG33–64" are used for the electrode cap and for the single-electrode headbox. The sockets "REF" and "GND" are for reference and ground electrodes. The bipolar channels 61–64 (see section 1.9) are connected to sockets EEG61+...EEG64–.

electrodes; ground and reference electrodes can also be connected via the headbox (see next paragraph).

The electrode cap (see Fig. 1.14) allows a convenient way of attaching a large number of electrodes to predefined places. For instructions how to use the cap, see Section 3.3. Caps with different electrode configurations

Fig. 1.14. The electrode cap.

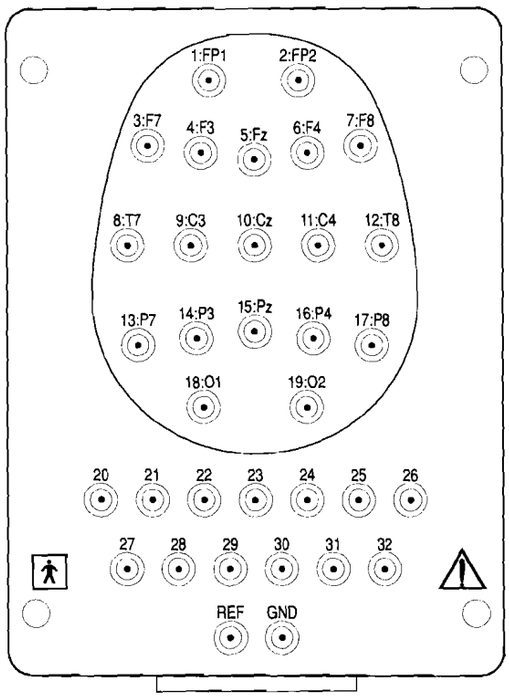


Fig. 1.15. The electrode headbox for 32 unipolar channels and reference and ground electrodes. Cable (separate) not shown.

are available upon request from Elekta Neuromag Oy. Alternatively, separate electrodes can be connected into a headbox (see Fig. 1.15). Using the electrode cap or headbox the subject can be conveniently prepared outside of the shielded room and the cap or headbox plugged in the electrode interface panel when the actual measurement starts.

1.9. EEG electronics

The preamplifier unit is located inside the gantry. It is fully software-controlled and it does not contain any switches, connectors, or other parts the operator needs to access.

The first 60 channels are always unipolar (single-ended), using common reference from reference electrode, and channels 61–64 are bipolar (differential). Differential channels can be used, e.g., to measure bipolar electrocardiographic (ECG), electromyographic (EMG), electro-oculographic (EOG) signals. Channels 61–64 are optionally configurable as unipolar (single-ended). This, however, requires corresponding hardware cabling in the electrode interface. Optionally, the number of channels can be inreased up to 128. Each additional group of 32 channels has 28 unipolar channels and 4 hardware configurable uni/bipolar channels.

For each channel, the gain and high-pass frequency can be set individually. A dc mode is also provided with a possibility for offset compensation. Unused channels can be deactivated by software, eliminating the need of grounding jumpers in input. A built-in test oscillator, with selectable amplitude and frequency, can also be connected by software individually for each channel. The interface of the channel control is explained in Section 8.4.

For potential equalization between the isolated preamplifier and the patient it is necessary to connect the patient to the isolated signal ground of the preamplifier over a ground (GND) electrode. However, to limit the patient current to a safe level, the preamplifier signal ground connection is provided through a current-limited ground driver connected to the GND terminal of the electrode interface panel.

The reference (REF) electrode is internally buffered and is normally selected as the common reference for all the single-ended channels. To facilitate common-mode disturbance rejection, e.g. to reduce line-frequency ripple and drifts, the reference electrode can also be connected as ac input to the ground-driver circuit to provide potential equalization between patient and preamplifier signal ground (so-called active grounding, effective only above 5 Hz). During measurements, both reference and ground electrodes must be connected. The place of the ground electrode is not critical, typically it is placed to some inactive area, like on the cheek. If the reference and ground electrodes are left out, common-mode potential of the subject with respect to the preamplifier common potential may saturate the amplifiers.

The feedthrough unit isolates the EEG front end from the data acquisition system with optocouplers, i.e., there is no galvanic contact to the rest of the electronics. The feedthrough unit also eliminates RF interference from the data acquisition system.

The feedthrough unit also houses the isolated power supply for the electrically floating front end and a control board for setting the preamplifier parameters.

The modules in the feedthrough unit do not contain any parts the operator needs to access nor are there any adjustable parameters.

The EEG data acquisition contains Signal Acquisition boards (SAM) with analog-to-digital converters and signal processors for filtering etc. on-line operations. The boards are connected to the real-time data acquisition computers for control and for data forwarding. All A/D conversions are started simultaneously, synchronized with MEG channels and the sampling rate is the same as in MEG channels.

The data acquisition system includes a dedicated optic link from the real-time data acquisition computer for controlling the preamplifiers.

For block and schematic diagrams refer to *Elekta Neuromag® System Hardware Technical Manual.*

1.10. Auxiliary electronics

The head position indicator system is based on coils (see Fig. 1.16) placed on known locations on the head. A single coil can be energized by a coil driver card with currents of different frequencies. The excitation signal is provided by the data acquisition system.

A 3-dimensional Fastrak digitizer (manufacturer: Polhemus, Inc, USA; see Fig. 1.17) is connected to the computer system. It is used in the preparation phase before MEG measurement to digitize the positions of the head position indicator coils as well as the landmarks on the head which are visible in the MRI scan. The locations of the landmarks are used

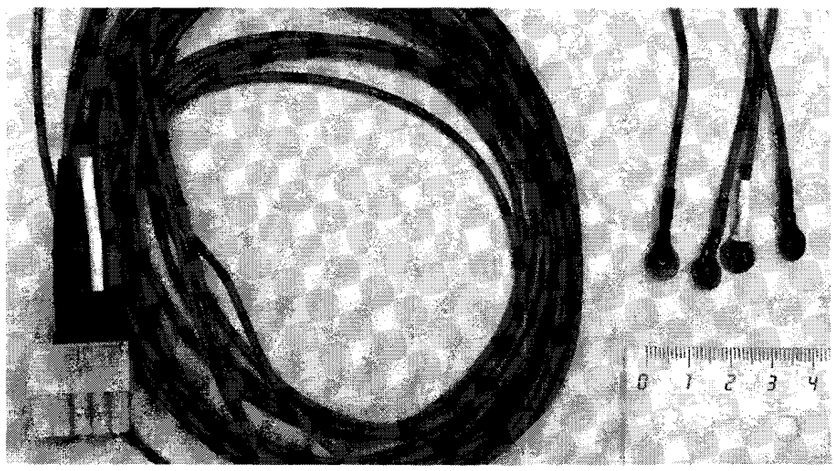


Fig. 1.16. Head position indicator coils.

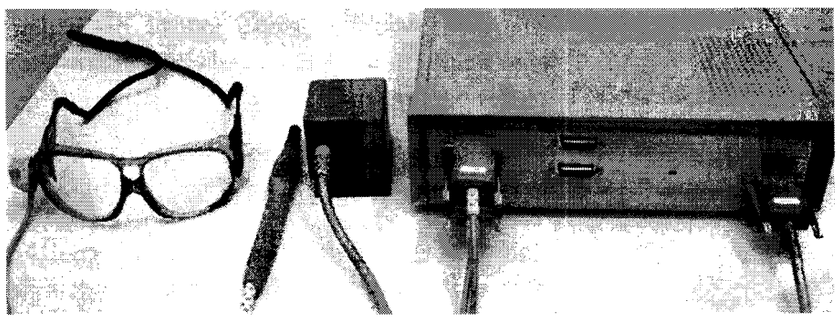


Fig. 1.17. 3-D digitizer unit. The transmitter coil (closest to the unit), digitizing pen, and goggles with separate reference receiver (leftmost) are also shown.

Fig. 1.18. Wooden chair for digitization.

to establishing a coordinate transformation between MEG and MRI (magnetic resonance imaging) data. To allow slight movements of the patient during the digitization, non-magnetic goggles with a separate reference receiver are provided. The transmitter of the 3-D digitizing system is attached to the back of the digitization chair (see Fig.1.18).

The liquid Helium level inside the Dewar is measured with a superconductive probe whose resistance is dependent on the length of the part immersed in liquid. The meter board reads the resistance and converts the reading into digital form which can be transferred to the computer. A local display is under the side cover of the gantry (see Fig. 1.19.). It is used for monitoring the liquid Helium level during Helium refilling.

Audio electronics interface (see Fig. 1.20.) is provided in the auxiliary electronics panel for the delivery of auditory stimuli. Two sets of head-

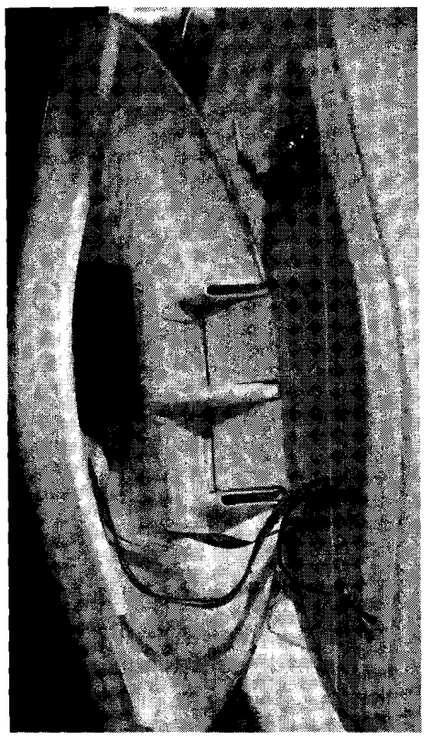


Fig. 1.19. The auxiliary electronics panel is under the gantry side cover. The liquid Helium level meter local display is mounted on the cover. Microphone for the optional intercom is seen in lower right corner.

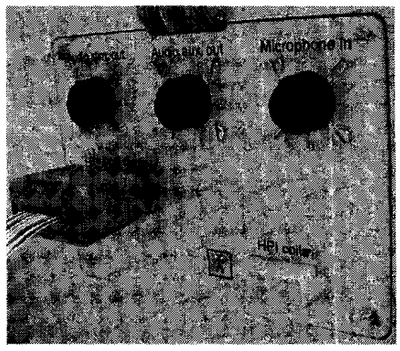


Fig. 1.20. The auxiliary electronics panel.

phones (stereo) can be connected, one for the patient and one for the eventual assistant. The microphone connector is for the intercom microphone.

A phantom is provided for checking the system performance (see Fig. 1.21). It contains 32 artificial dipoles and four head-position-indicator coils. The phantom is based on the mathematical fact that an equilateral triangular line current produces equivalent magnetic field distribution to that of a tangential current dipole in a spherical conductor, provided that the vertex of the triangle is at the origin of the sphere.

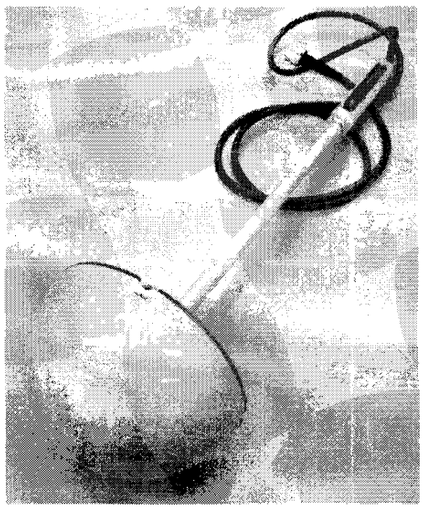


Fig. 1.21. The phantom.

An optional closed circuit TV-monitoring system (CCTV) is provided for on-line monitoring the patient inside the magnetically shielded room during the measurement. A two-way voice intercommunicator (option) is used for communicating with the patient inside the magnetically shielded room during the measurement.

1.11. Interface to stimulus electronics

A 16-channel trigger pulse (digital) input-output interface is provided for synchronizing the measurement software and stimulators (not supplied with the standard system) used for evoked-response studies. The interface unit is optically isolated from the main electronics and data acquisition system.

The RF-shielded stimulus electronics cabinet is used to prevent possible RF disturbances caused by stimulus devices from entering the magnetically shielded room. RF-filtered feedthroughs are available between the inside and the outside of the cabinet. Active digital circuitry, e.g., a computer inside the stimulus cabinet should be avoided.

1.12. Data acquisition system

The data acquisition system includes interface units to import and export digital signals. It imports the 306 MEG channels and the 64 EEG channels. In addition, it handles the control of the MEG and EEG electronics as well as the timing parameters of the system. The system also takes care of the trigger signals.

The data acquisition system consists of parallel real-time computers that are connected to a single acquisition workstation via an Ethernet Switch.

Normally, the operations of the real-time computers need not be accessed directly by the user. For schematic and block diagrams, refer to *Elekta Neuromag® System Hardware Technical Manual.*

1.13. Computer system

The standard system configuration typically includes two UNIX workstations: one for performing and controlling measurements and on-line processing (acquisition workstation) and the other for off-line analysis of data (analysis workstation). Additional mass storage and output devices etc. can be added to the system according to need. For schematic and block diagrams, refer to *Elekta Neuromag® System Hardware Technical Manual.* See also Fig 1.1.

1.14. Cryogenic equipment

A siphon is used to transfer liquid Helium from a storage container to the Dewar when a refill is needed. It is a flexible, vacuum-insulated double-wall tube.

The Helium gas evaporating from the Dewar is routed typically via a special exhaust system to the outside air or to a gas-recovery system (if available). If installed, the exhaust system comprises a Helium boiloff valve unit for connecting the Dewar exhaust hose and storage Dewar exhaust hose to a Helium boiloff feedthrough tube connected to a check-valve. This is normally connected via a heat exchanger to a gas meter (optional).

The system also contains a safety vent to outside of the building, comprising flexible safety exhaust duct and a Helium safety exhaust duct feedthrough.

A block diagram of the liquid and gaseous Helium systems is shown in Fig. 1.22.

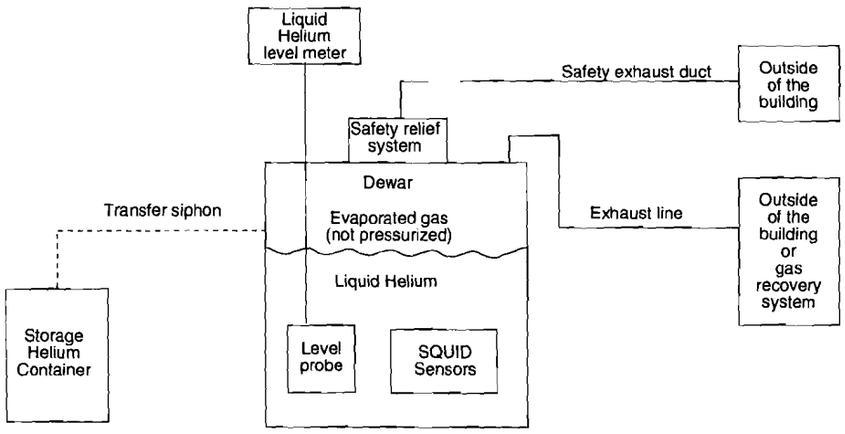


Fig. 1.22. Block diagram of the liquid and gaseous helium systems..

2. Safety instructions and precautions

CAUTION! This section contains important information concerning the safe use of the system and maintaining reliable operation. Read the instructions entirely before using the system.

2.1. Use of liquid Helium

The Dewar is a vacuum-insulated vessel containing liquid Helium at a cryogenic temperature. Since the cold liquid is potentially dangerous, certain precautions must be made in order to assure completely safe operation of the device.

2.1.1. Properties of Helium

- Helium liquid or gas is nonflammable and nontoxic
- Helium is one of the noble gases (He, Ne, Ar, Kr, Ra)
- Helium gas is odorless and colorless
- Helium gas is seven times lighter than air
- Helium gas is not life-supporting: it may replace air thus reducing the relative oxygen content in closed rooms if evaporated rapidly in large quantities, resulting in a risk of suffocation
- Boiling point 4.2 K (–269°C or -452°F)
- Density of liquid 0.125 kg/liter
- The liquid evaporates very easily (latent heat of evaporation 20.9 kJ/kg = 2.6 kJ/liter).
- One liter liquid corresponds to approx. 750 liters of gas (+20°C, 101,3 kPa).
- Skin contact with liquid or cold gas or cooled objects may cause severe frostbite
- Flow of cold Helium gas makes a very good thermal contact with any surface it passes by; unprotected skin cools below freezing point in seconds
- Dangerous pressures may arise as a result of rapid vaporization inside closed vessels

- Liquid Helium can cryopump other gases such as nitrogen, oxygen, water vapor etc., which at liquid Helium temperature solidify. This may lead to blocking of the vents and consequently buildup of dangerous pressures in cryogenic vessels. See Sect. 4.1.2.

2.1.2. Structural safety

- The Dewar has a good thermal insulation to minimize He-boil-off.
- The insulating vacuum is properly sealed and all parts are fabricated leak-tight.
- Because of the thermal insulation, all parts of the Dewar that may come into contact with the user remain at room temperature at all times during normal operation.
- The cooling capacity of the evaporating cold Helium gas is employed to partly minimize the unavoidable heat leak from room temperature to the cryogenic temperature. Therefore, under operating conditions the outflowing exhaust gas is warmed up to essentially room temperature before leaving the Dewar. However, during increased outflow occurring normally only during liquid Helium refills, the gas exiting from Dewar may be extremely cold. Skin contact with the exhaust line tubings should then be avoided.
- The Helium space of the Dewar is vented to prevent buildup of pressure due to evaporating liquid Helium.
- The outflowing gas is directed via an exhaust line provided with a backlash valve to open air outside the building or to gas-recovery system (if applicable).
- The dedicated exhaust line together with the sealing of the He-space of the Dewar prevent cryopumping of other gases from the atmosphere.
- The top flange is equipped with pressure relief valve and a rupturing membrane which will let gas out should the pressure inside the Dewar rise for some reason. Also, a pressure gauge is attached on the top flange.
- The pressure relief system which is based on rupturing membrane vents via a separate safety exhaust duct to outside of the building.
- The gantry is designed to keep the Dewar in proper position.

CAUTION! The structural integrity of the Dewar should not be damaged in any way. Absolutely no holes may be drilled to the Dewar.

- Hard shocks to the Dewar must be avoided.

CAUTION! The Dewar vacuum must not be opened to atmospheric pressure under any circumstances.

- The Dewar is equipped with a vacuum lock valve and is sealed by means of a blind flange to prevent accidental opening and leakage

through the vacuum lock. The vacuum lock is operated with a separate vacuum-valve adapter.

CAUTION! The exhaust line must be open at all times

- The exhaust line should be reasonably leaktight and lead out of the magnetically shielded room to open air or to the recovery system.
- The magnetically shielded room must be properly ventilated. For details, see *Elekta Neuromag® Site Planning Guide*.
- The overpressure inside the Dewar (with respect to atmospheric pressure) should be kept below 10 kPa (0.1 bar) even during refill. Should the pressure rise, a safety relief valve will open at 10 kPa (0.1 bar). If for some reason the pressure rises even further, a rupturing membrane will break approximately at 60 kPa (0.6 bar), letting gaseous Helium to escape via the safety exhaust duct to the outside of the building.
- The fixed L-siphon used in the Helium refills and located on top of the Dewar is normally sealed with a plug that has an additional relief valve which effectively vents the cold Helium space directly into the atmosphere through the siphon in the unlikely case all other exhaust routes get blocked.
- When transferring liquid Helium, transfer instructions should be obeyed (see chapter 4.4).

CAUTION! To prevent frostbite, avoid contact with liquid Helium or exhaust gas or any objects that have recently been in direct contact with liquid or evaporated gas. Wear protective gloves and safety goggles.

- Transfer of liquid Helium can be carried out by a single person. For safety reasons it is, however, highly recommended that another person is present to assist or call for help in possible abnormal conditions. This is especially important if the transfer is carried out off-hours.

CAUTION! Do not leave anybody alone inside a closed magnetically shielded room without the presence of another person outside the room!

- The liquid Helium level and boil-off rate should be monitored regularly. Substantial increase of boiloff rate may indicate the need to re-evacuate the vacuum. The vacuum pump-out must be left to trained service personnel.
- See also Section 2.1.3 concerning cryopumping.

2.1.3. Cryopumping

At liquid Helium temperature all common materials are solid. This means that the vapor pressure of for example the atmospheric gases (nitrogen, oxygen, water) is practically zero in any volume containing liquid

Helium which leads to *cryopumping* of these gases: any Helium vessel left open to atmosphere will very effectively suck in large amounts of these gases. Water freezes and may block the Helium vessel or a transfer siphon. Oxygen in the probe unit Dewar causes large irregular low frequency drifts of MEG signals because the magnetic susceptibility of the paramagnetic oxygen in its solid form is very high.

NOTE! To prevent cryopumping, observe the following precautions:

- All Helium vessels must be sealed from the atmosphere and properly vented, via a back flow valve or a sufficiently long and narrow exhaust tube.
- Do not leave the fixed L-siphon at the top of the Dewar open. Block the opening with the dedicated plug when not transferring Helium.
- Do not leave the boil-off tube vent directly into the room. Use silicon hose to lead the exhaust vent out from the magnetically shielded room. If the hose breaks during transfer, replace it with a new hose as soon as possible
- Do not remove the fixed siphon or the boil-off tube from the top plate. The openings must be plugged with rubber bungs (provided in the Cryogenic Accessory Kit) if the fixed siphon or the boil-off tube are ever removed even for a short while.
- If the safety exhaust rupture membrane accidentally breaks, the opening must be plugged with a large rubber bung and the membrane replaced (provided in the Cryogenic Accessory Kit) .

2.2. Electrical safety

All Elekta Neuromag® SQUID sensor electronics is operated using low-voltage (max. 15 $V^{=}$, 24 $V^{\sim}$) power supplies connected to the mains through an isolation transformer. To avoid electrical interference, most parts are shielded and grounded (class I according to IEC 60601-1). The probe unit is operated inside a magnetically shielded room to avoid electromagnetic interference.

2.2.1. Subject connections

All applied parts of MEG equipment connected to the subject are made of electrically insulating materials only. They are classified as BF (body floating) type according to IEC 60601-1.

Helmet-shaped sensor assembly is located inside a double-walled isolating (fiber reinforced plastic, vacuum gap) Dewar vessel, making no electrical contact to the subject. The device does not generate radiation. During the experiment, it is not possible for the subject to get in contact with grounded parts.

Head position coils on small printed circuit boards are spiral-shaped. The coils are connected to isolated leads and cast with isolating epoxy. No electrical contact to the subject is thus made. Current fed to coils is typ. 70 μA, and the resulting field less than 1 nT.

The EEG subsystem contains an applied part of BF type (body floating) in galvanic contact with the subject. The applied part has been carefully designed and built to fulfill the safety regulations as set by international standards IEC60601-1 and IEC60601-2 . The EEG preamplifiers are optically isolated, and the power supply of the EEG preamplifiers is provided with safety isolation transformer.

CAUTION! To eliminate any risk of electrical shock hazard the EEG subsystem must be properly installed by authorized service personnel and used as part of the Elekta Neuromag® system according to manuals and assembly instructions. Internal cabling must not be changed.

NOTE! The EEG subsystem cannot be used as a standalone unit outside of the magnetically shielded room.

There are no internal operator-serviceable parts inside. Head position indicator coils, electrode caps, headboxes, and electrode interface in the side panel of the gantry are the only operator-accessible parts of the EEG subsystem. Use only headboxes and electrode caps supplied with the system or available as options.

2.2.2. Power supplies and grounding

CAUTION! The power supply of the electronics must be connected only to the power outlets inside the electronics cabinet which are connected to mains via an isolation transformer. Also, internal power cabling must not be changed.

CAUTION! The 3-D digitizer power supply unit must be connected to mains via an isolation transformer supplied with the Elekta Neuromag® system.

The main electronics is powered through medical safety-isolating transformer connected to electronics cabinet outlets. Therefore, internal power cabling must not be changed. For schematic diagrams of the powering, refer to *Elekta Neuromag® System Hardware Technical Manual.*

CAUTION! The isolation transformers also provide step-up or step-down voltage conversion if needed. Inside the main electronics cabinet the mains voltage is 230 V~.

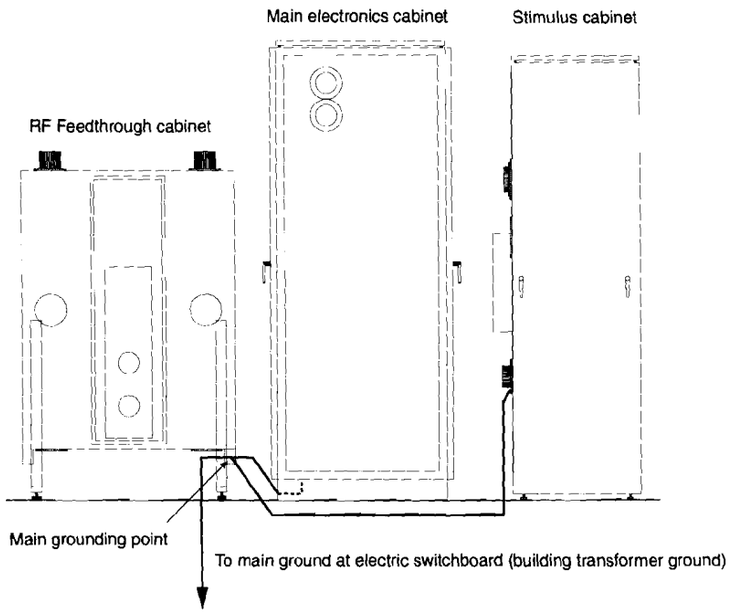

Main electronics cabinet
Stimulus cabinet
RF Feedthrough cabinet
Main grounding point
To main ground at electric switchboard (building transformer ground)

Figure 2.1. Grounding of the system.

CAUTION! The RF line filters in stimulus cabinet contain large capacitors. Thus voltage may remain across terminals even after the power has been switched off from the filter. The filters have built-in resistors which discharge the terminals in less than 10 seconds. All shielding covers must be in place before applying power to the filter. The filters may only be installed permanently; mains plug connection of the filter is prohibited.

The power supply units are protected by mains (primary) fuses. All fuses are accessible at the back plane of the MEG preamplifier power supply unit with the correct values of the fuses marked in the immediate vicinity. A "T" before the rated current in amperes indicates slow (time-lag, slow blow) type and a "F" fast type. If no type has been indicated, use fast type fuses.

CAUTION! To avoid risk of fire and of electric shock ALWAYS use only correct-rated fuses as replacement.

The system, except for the EEG applied parts discussed below, is permanently grounded (class I equipment according to IEC 60601-1) at a single point (main grounding point) located at the filter unit cabinet between the electronics cabinet and the magnetically shielded room (see Fig. 2.1).

CAUTION! The grounding cables must not be disconnected.

NOTE! The system must not be grounded to any other place than the main grounding point. This is very important since otherwise ground loops will be formed resulting in artefacts in the measurements.

The grounding system of Elekta Neuromag® has been carefully designed and realized. Do not add any equipment to the system or change any cabling without considering the possible side-effects. If in any doubt, contact Elekta Neuromag.

The applied part of EEG is electrically floating, i.e., isolated from ground. It must not be grounded in any circumstances. For potential equalization between the isolated preamplifier and the patient it is necessary to connect the patient to the isolated signal ground of the preamplifier.For that purpose, a terminal labelled "GND" is available in the electrode interface panel. To limit the patient current flowing through that terminal to a safe level, the preamplifier signal ground connection is provided through a current-limited ground driver of the preamplifier (see chapter 1.9 and Appendix). The isolated preamplifier signal ground is not directly accessible when headboxes and electrode caps supplied with the system or available as options are used. The isolated preamplifier signal ground, which is only available internally, must not be connected directly to humans as the maximum allowable current may be exceeded in a fault condition.

CAUTION! Do not connect any of the electrode inputs of the side panel or the headbox to actual ground (e.g. the wall of the magnetically shielded room). Care must be exercised to avoid contact of conducting parts of the electrodes, including REF and GND electrodes, to ground or other conducting parts which may be grounded or become live at mains voltage. Do not ground subject to actual ground (e.g. the wall of the magnetically shielded room). Do not place conducting grounded objects near the subject that he/she may touch while connected to the equipment.

2.2.3. Auxiliary user-supplied equipment

To avoid risk of electrical shock, equipment supplied by the user and connected to humans must comply with isolation requirements similar to or better than this system. For connection of these devices, isolated and filtered power outlets are provided in the stimulus cabinet. Maximum current available is 10 A (total).

CAUTION! The applied parts of user-supplied equipment must be of BF or CF type (cardiac floating) and they must fulfill the norms according to IEC 60601–1 for medical electrical equipment. Although the individual devices fulfill the leakage current requirements set forth in standards, a possible hazard exists caused by the summation of leakage currents when several pieces of equipment are interconnected. Also, other equipment connected to the same stimulus trigger interface unit must fulfill the requirements of IEC 60601–1.

The power outlets in the electronics and stimulator cabinets connected to the isolation transformers (if installed) may only be used for the connection of system components or equipment needed during service and maintenance operations or for compatible user-supplied auxiliary equipment (stimulus cabinet).

2.2.4. Defibrillators

NOTE! The EEG subsystem is not protected against cardiac defibrillator discharge. Damage to the front end may result if a defibrillator is used on a subject connected to the electroencephalograph. In case of a need for defibrillation, disconnect the electrodes if possible. This is carried out quickly by unplugging the electrode cap or headbox connectors and the eventual single electrodes from the electrode interface panel.

The system cannot be used with treatment devices feeding energy to the subject such as high-frequency surgical equipment.

2.3. Mechanical safety

The weight of the fully loaded Dewar including liquid helium and the Dewar supporting cradle moving with the sensors is approximately 200 kg. To ensure that the Dewar is prevented from falling down from the seated measurement position under any circumstances it is equipped with two completely separate and parallel support mechanisms both of which alone can withstand at least a fourfold overload compared with the normal working condition.

CAUTION! The dewar position must not be changed while patient or patient chair is under the gantry.

The patient is released from the helmet in the seated measurement position by releasing the elevation mechanism of the chair and pulling the chair from underneath the Dewar. For instructions, see chapter 5.5.

Additionally, it is possible in the supine measurement position to get out from the helmet by pulling strongly the upper patient bed even if it is locked (see Chapter 5.4).

Have the unit regularly serviced according to the maintenance program (see chapter 8.1). This must be accomplished by trained service personnel only.

2.4. Trapped flux in the sensors

Strong magnetic fields in the vicinity of the sensors may cause magnetic flux to be trapped in the superconducting thin films due to their limited

capability of repelling magnetic flux completely. In particular, if magnetized objects like magnetic electrodes or hairpins are brought inside the helmet against the surface, flux trapping may occur.

Trapped magnetic flux in the dc SQUID manifests itself as a greatly reduced modulation depth of the flux vs. current characteristics. The point of operation also changes. As a result, the SQUID feedback loop may not lock any more after flux trapping or the noise level may be increased, resulting in deteroriated signal quality. Flux trapped in the flux transformer structures may manifest itself as discrete jumps in the output level causing rejections of evoked data.

Normal performance can, however, be recovered by detrapping (see 2.4.2). In the detrepping procedure, the trapped flux is removed by increasing the temperature above superconductive transition temperature using heaters mounted on each triple sensor element. In order to minimize the delay due to the flux detrapping in a measurement certain precautions should be noticed.

2.4.1. Preventive measures

The only way of avoiding trapped flux is to avoid bringing permanently magnetized objects in the vicinity of the Dewar. Therefore:

- Items unnecessary for the measurement should be removed (hairpins, jewelry, eyeglasses etc.)
- Test the objects worn by the subject, particularly on the head like electrodes, before the subject goes under the Dewar. In particular, test a new batch of electrodes before they are taken into use.
- To test whether an object is magnetic or not: First, test whether the object attaches to an ordinary bar magnet. If it does, the object is magnetic and it should absolutely be kept out of the magnetically shielded room. If the object is not attracted to the bar magnet, do a test with the Elekta Neuromag® system. Ask for someone to assist you in the test. First, carefully remove everything possibly magnetic from your pockets, wrist watch, belt, eyeglasses etc. Go with the object to be tested inside the magnetically shielded room and close the door. Ask the assisting person to start acquisition of data and watch the raw data display as described in the *Data Acquisition User's Guide*. Wave your bare hand under the magnetometer helmet to verify that it does not cause any noticeable signals. Then, take the object under test in your hand and wave it under the helmet to see whether it causes any disturbances. If it does, it is too magnetic for MEG and should be avoided in measurements.

NOTE! Do not bring the bar magnet inside or even close to the magnetically shielded room. Do not attach the bar magnet to the magnetically shielded room wall as it will magnetize the wall material to saturation, severely degrading the shielding performance.

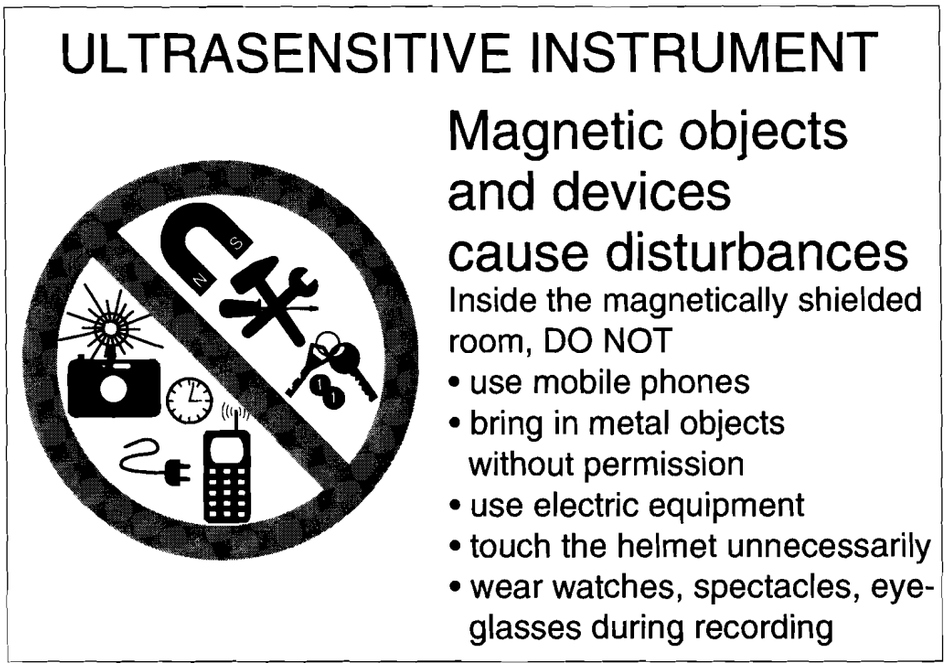

ULTRASENSITIVE INSTRUMENT
Magnetic objects and devices cause disturbances
Inside the magnetically shielded room, DO NOT
• use mobile phones
• bring in metal objects without permission
• use electric equipment
• touch the helmet unnecessarily
• wear watches, spectacles, eye-glasses during recording

Figure 2.2. Recommended warning of magnetic objects.

- Avoid bringing heavy tools into the shielded room. If it is absolutely necessary, keep them as far as possible from the sensors. Nonmagnetic tools are commercially available.
- Avoid using electric motors inside the room. If it is absolutely necessary, keep them and their power cables as far as possible from the gantry.
- Do not use electronic flash inside the magnetically shielded room.
- Avoid discharges of static electricity on any part of the probe unit. The humidity in the magnetically shielded room should be controlled according to *Elekta Neuromag® Site Planning Guide*.
- It is recommended that the user is warned about magnetic objects and devices with a sign posted at the entrance of the magnetically shielded room (see Fig. 2.2).
- The electrodes and electrode caps should be stored carefully, preferably hanging in dry room air. Do not keep the electrodes and the caps on a table where they might be contaminated with magnetic particles. Wash them carefully after each use (see cleaning instructions in Chapter 8.7).

NOTE! The connectors used in the headbox may contain a thin intermetallic layer of magnetic material. To avoid magnetic artefacts during MEG measurements, do not bring the headbox close to the helmet and keep it steady. Put it on the bed or on the removable table of the chair at least 0,5 m away from the helmet. Do not put it in the subject's lap or on the chest as movement caused by respiration may produce an artefact.

2.4.2. Detrapping

The Elekta Neuromag® triple sensors are equipped with heaters. To detrap a sensor, invoke Tuner program from the Tools Menu of the Data acquisition program. Then, activate the heater from the tuner program. You can heat any sensor element (three channels) at a time or all sensor elements sequentially ("heat all" command). Detrapping all channels takes about one minute. Measure the noise level of the sensor, and, if necessary retune the sensor. For further details, refer to *Sensor Tuner User's Guide.*

2.5. EEG Electrodes

measurements, the choice of proper electrode materials and paste/gel is very important.

As the electrodes and the electrode cap are very close to the magnetometer sensors, they are particulary prone to cause magnetic artefacts. Even a thin layer of magnetic material or a small particle of ferromagnetic dust can cause magnetic artefacts to one or more MEG channels.

When operated in dc coupled mode electrochemical battery potentials generated in electrodes are directly coupled into the preamplifier. This causes a risk of saturating the amplifiers, even in ac coupled mode since frontmost amplification stages are internally always dc coupled. Furthermore, if the connection between the electrode and skin is not stable movements tend to change the electrode potential and cause severe low frequency noise or drift.

NOTE! The use of Ag/AgCl electrodes is recommended since they are known to minimize the electrochemical battery potentials, they are non-magnetic (see Chapter 2.4.), and relatively easy to obtain. It is best to have all electrodes made of same material and to use the same electrode paste/gel. Specifically, all the electrodes of the unipolar channels and the reference channel must be of same material and use the same electrode paste/gel. In order to maintain good performance, the AgCl coating must cover the whole electrode surface; worn or scratched coating may result in electrochemical battery potentials saturating the amplifier.

NOTE! Gold-coated electrodes are not recommended since most often they contain a magnetic intermetal layer making them incompatible with MEG measurements. Also, some commercially available Ag/AgCl electrodes contain nickel or other magnetic material; all electrodes must therefore be tested before using them with MEG (see Chapter 2.4.1.).

The electrode caps supplied with the system are made of sintered Ag/AgCl and tested to be non-magnetic. Note that electrode caps available commercially elsewhere may be incompatible with MEG.

For cleaning, disinfecting, and maintenance of the electrodes, refer to Section 8.7.

2.6. Electromagnetic compatibility

NOTE! Medical electrical equipment needs special precautions regarding electromagnetic compatibility (EMC). It needs to be installed and put into service according to the EMC information provided in this manual and *Elekta Neuromag® System Hardware Technical Manual.*

NOTE! Portable and mobile RF communications equipment can affect medical electrical equipment.

2.6.1. Electromagnetic interference

The probe unit including the EEG preamplifiers and the electrode interface is placed inside a magnetically shielded room, and all cables to the inside of the room have been carefully filtered. This immunity can, however, easily be corrupted by careless setups of additional equipment. This is especially important for MEG recordings.

NOTE! RF intereference may deteriorate signal quality and lead to incorrect results.

To maintain high level of electromagnetic interference immunity, all cables coming to the magnetically shielded room must be properly filtered. Radiofrequency transmitters like mobile phones as well as mains operated devices and active digital electronics inside the magnetically shielded room must be avoided altogether. Use of the stimulator cabinet outside of the magnetically shielded room is highly recommended for other equipment. There is a direct access from the stimulator cabinet to the inside of the shielded room, and the stimulator cabinet is equipped with signal and mains feedthrough filters. Place, for example, the isolation units of somatosensory stimulators inside the stimulus cabinet. To avoid radiated intereference via cabling, digital electronics which is active during measurement should, however, be avoided also inside the stimulus cabinet.

2.6.2. Electrostatic discharges

The Dewar, gantry, and the electronics contain static electricity sensitive components. To prevent flux trapping or permanent damage certain precautions are necessary. Pins or connectors marked with the ESD symbol should not be touched and connections should not be made to these connectors unless ESD precautionary procedures are used.

NOTE! It is recommended that the meaning of the ESD symbol should be explained to all staff involved in the use of the system. They should also receive training covering the precautionary procedures described below.

- The properly grounded and shielded cabinets and racks are the most effective shield against damage. In normal operation, there are no parts inside the MEG electronics cabinet or the gantry top part the user needs to access. Do not remove covers and do keep the cabinet doors closed.
- Do not touch the pins of connectors or cables, the electronics backplane, or the electronics boards before grounding yourself properly.
- Ground yourself with a grounding wrist strap or by touching any metallic parts of the magnetically shielded room or inside the electronics cabinets. To minimize the danger of electric shock it is recommended to use a grounding strap specially made for this purpose that contains a built-in series resistance. Connect it to the cabinet frame or magnetically shielded room wall.
- To prevent static electricity discharge to preamplifiers while connecting or disconnecting head position indicator coils, EEG electrodes or electrode caps, the relative humidity of the air inside the magnetically shielded room should be over 30%, preferably between 40% and 70% (see Site Planning Guide).
- Leave electronics service to trained service personnel.
- Do not disconnect the electronics cables from the top flange of the probe unit or any other internal cables.
- Handle electronics boards only on static-electricity-free surfaces
- All strain relievers and covers must be in place before connecting power to the electronics.
- Follow proper power-up instructions (see Chapter 6.3).

2.7. Other precautions

- Never pull out or push in electronics boards with power on. Switch off the power before moving or inserting any cards.

3. A typical measurement with the system

3.1. Preliminaries

If display of the MEG localization results on the anatomical MRI scans is required, the MRI of the subject should be acquired and transferred into the system. This can be carried out after a measurement as well; MR imaging after measurment is even recommended if the patient has dental braces, fills or the like that could be permanently magnetized during MR scanning. To align coordinate frames, nasion and preauricular points should be made clearly visible in the MRI by, e.g., attaching on them small oil capsules visible in anatomical T1-weighted MR images.

3.2. Pre-experiment measures

Open the door of the magnetically shielded room. Check the inside of the room and remove unnecessary items. All-metallic large objects and ferromagnetic objects should be avoided altogether. Keep the room, and especially the chair, bed, and probe unit clean. Adjust the gantry into either upright or supine position as described in section 5.3.

Log in the computer and start the measurement session as described in the *Data Acquisition User's Manual.* Check the liquid Helium level from computer if needed. If applicable, set up the stimulation equipment for the particular experiment and test the stimuli.

NOTE! To prevent incorrect interpretation of measurement results, it is important to verify that physical stimuli and their planned trigger line assignments match, e.g. there are no swaps or mixups.

Set up appropriate values for the acquisition parameters like sampling rates, passbands etc. on the acquisition program. Enter the subject data and experiment data. Set up on-line averaging if applicable.

The active MEG and EEG channels and the sampling rate as well as the low-pass filter are selected from the acquisition setup dialog. MEG and EEG signals are recorded synchronously, using the same low-pass and sampling rate settings.The acquisition program also controls digital high-pass filtering of MEG signals. However, for EEG signals the high-pass

filter is analog and realized in the preamplifier. The EEG preamplifier parameters (like gain and analog high-pass filter) are initially set to their site-configurable defaults values. If necessary, they can be controlled using the Squiddler-EEG utility program described in Section 8.4. The gain and high-pass filter of each channel can be set separately,and data acquisition software module "collector" (versions later than 4.20) recognizes the gain automatically. Typical default settings assume default gains of 5000 for unipolar and 500 or 150 for bipolar channels (depending on software configuration), respectively and 0.1 Hz for high-pass filter.

NOTE! To prevent noisy signals from disturbing the analysis, switch noisy MEG or EEG channels as well as unused EEG channels off from data acquisition. Noisy MEG channels may interfere with other channels when on-line noise reduction is used. Several unused but active EEG channels may cause spurious oscillations of isolated signal ground of the preamplifier, which propagate to all EEG channels. The EEG preamplifiers have built-in circuitry to ground the unused channels right after the first amplification stage. The acquisition control software automatically controls this circuitry.

When EEG is not used at all, it is recommended to also connect signal terminator blocks (provided with the system) to the D37 connectors. Remember to remove the blocks even when using only single electrodes connected to the separate sockets at the gantry panel as the sockets are connected in parallel with the second D37 connector (EEG33–EEG64) pins.

For details of the data acquisition software, see *Data Acquisition User's Manual.*

3.3. Preparation of the subject

To avoid magnetic artefacts, ask the subject to remove all metal objects he/she is wearing. Remember especially hairpins, the watch, and jewelry worn on the head. Wearing special clothing without any hooks etc. may be necessary since all ferromagnetic materials cause magnetic artefacts. Attach head position indicator (HPI) coils and eventual EOG and EEG electrodes or caps as described below.

CAUTION! After electrodes have been attached onto the subject's head, avoid contact of conducting parts of the electrodes, including reference (REF) and isolated preamplifier signal ground (GND) electrodes, to actual ground or other conducting parts which may be grounded or become live at mains voltage. Do not ground subject to actual ground (e.g. the wall of the magnetically shielded room). Do not place conducting grounded objects near the subject that he/she may touch while connected to the equipment.

Fig. 3.1. HPI coils in place. Note that the subject is not yet in the actual measurement position.

3.3.1. Attaching the head position indicator coils

Take a head position indicator (HPI) coil set with three to five coils. Typically, the coil sets have four coils preassembled. If necessary, add an additional coil by inserting the coil connector pins from the back of the HPI connector until they click in place. Check that the coils are OK by connecting the coil set connector to the HPI coil tester (optional accessory) or use an ordinary ohm-meter to check the continuity of the HPI-coils. The corresponding green LEDs should be lit or the coil resistance less than 10 Ω. If any coil is broken, a new coil set must be used. A HPI spare part kit for repair is also available.

Attach the HPI coils to the subject using skin tape (such as 3M™ Micropore™ Tape 3M Corporation, St. Paul, MN, USA, or equivalent) or adhesive washers (such as Gereonics 450097, Gereonics Inc, Escondido, CA, USA, or equivalent). One of the coils will be placed frontally up in the middle near the hair line while two others behind the ears as high as possible near the hair front on the left and right hemispheres. Optionally, one or two additional coils can be placed near the vertex. Usually, the coils should be placed high enough that they will be well inside the sensor array area.

CAUTION! Do not use conducting EEG paste to attach HPI coils.

If an electrode cap is used, they can be put on the cap, optionally also tangling the HPI coil cables with the cap electrode wires so that the coils do not detach or move if the cable of a coil is accidentally pulled.

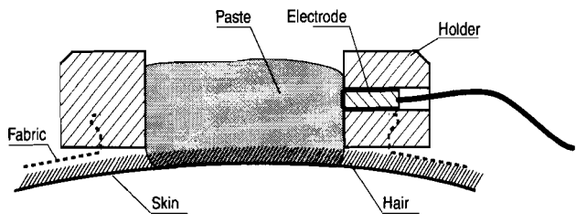


Fig. 3.2. Cross-section of the electrode-skin interface of the electrode cap.

3.3.2. Attaching the electrode cap

The electrode cap is made of elastic fabric. The Ag/AgCl electrodes snap into plastic electrode holders on the cap. A 6-mm opening in the plastic holder provides easy access to the skin underneath. No scratching with a needle is needed.

Attach the cap to the subject's head and tighten the straps under the jaw so that the cap sits tightly but comfortably (see Fig. 1.14). Apply a liquid electrode gel such as OmniPrep® Skin Preparation (D. O. Weaver & Co., Aurora, CO, USA) to e.g. a cotton swab. This paste includes particles to abrade the skin. Rub the skin gently, ensuring that the gel wets the skin even if the hair is very thick. Do not over-abrade, however. Prepare all electrodes in the same manner. After that, inject hardening electrode paste, e.g. Grass® EC2™ (Grass Instruments, Quincy, MA, USA) with a syringe to form the actual bridging from the skin to the electrode (see also Fig. 3.2). Do not use a hypodermic needle on the syringe. Press the electrode with your fingers against the skin while squeezing the syringe. The electrode paste hardens quite rapidly. A piece of paper tissue compressed on the electrode helps in drying the paste. The paste can, however, be washed away easily with ordinary soap or mild dish care detergent such as Fairy™ and water. Repeat this procedure for each electrode opening. Refer also to the instructions given by the electrode/ gel manufacturers.

CAUTION! Avoid getting the paste or gel to the eyes or mouth. Use only non-toxic pastes approved for clinical use.

After this, attach the reference (REF) and ground (GND) electrodes (single electrodes) as explained in the next chapter.

3.3.3. Attaching single electrodes

Instead of the electrode cap, single electrodes can be used, especially if only a few are required. In addition, single electrodes are used for bipolar channels and for the reference and ground electrodes, also when electrode cap is employed.

The reference electrode acts as a reference for all the unipolar channels of the cap, and the ground electrode is used to set the subject to common potential with the preamplifiers to reduce common-mode interference. Line frequency ripple and drift may be further reduced by using active grounding as described in Chapter 1.9. Both the reference and ground electrodes must be connected. Place the reference electrode according to the electrode derivation used. The place of the ground electrode is not critical, typically it is placed to some inactive area, like cheek. In SEF measurements, place the ground electrode close to the stimulating electrode to minimize artifacts.

Prepare the skin with an abrasive skin cleaner such as OmniPrep® Skin Preparation (D. O. Weaver & Co., Aurora, CO, USA) or with alcohol using a cotton swab. Apply electrode paste, e.g., Grass EC2 (Grass Instruments, Quincy, MA, USA) to the electrode and put it in place. Press the electrode with a small piece of paper tissue until the paste is hard enough to keep the electrode in place. Special adhesive washers, such as Gereonics 450097 (Gereonics Inc, Escondido, CA, USA) or skin tape such as 3M™ Micropore™ Tape (3M Corporation, St. Paul, MN, USA) can also be used if applicable. After use, the electrodes can be cleaned following the instructions given by the electrode manufacturer.

CAUTION! Avoid getting the paste or gel to the eyes or mouth.Use only non-toxic pastes approved for clinical use.

Before entering the magnetically shielded room it is recommended to check the electrode impedances using an ac-coupled meter such as Grass F-EZM5 (Grass Instruments, Quincy, MA, USA), if available. The preamplifier is stable for electrode impedances up to 50 kΩ. However, to minimize low-frequency noise and line interference, electrode impedances should be below 20 kΩ. For optimum performance, impedances below 10 kΩ are recommended.

The single unipolar, reference, and ground electrodes can be plugged in the headbox during the preparation. Bipolar electrodes such as for EOG and EMG are connected to the electrode interface panel on the side panel of the gantry inside the magnetically sielded room.

3.3.4. Digitization of head position indicator coils

Determination of the position of the head position indicator coils and optional head shape digitization is performed with the help of Polhemus 3-D digitizer included in the system. Digitization is performed outside of the magnetically shielded room,

CAUTION! The 3-D digitizer power supply unit must be connected to mains via an isolation transformer supplied with the Elekta Neuromag® system.

Fig. 3.4. The head digitization goggles with additional receiver.

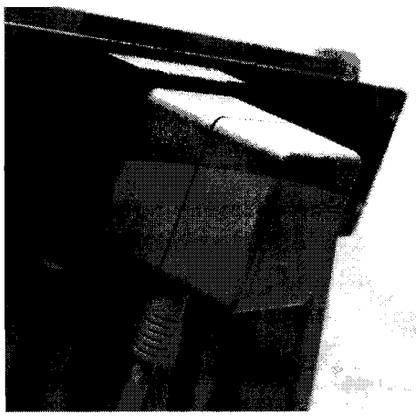


Fig. 3.5. The transmitter attached to the chair.

Have the subject seated in the dedicated digitization chair. Place the goggles firmly on the subject's head and tighten the strap (see Fig. 3.4). Alternatively, the digitization may be performed while lying on the bed. For using the bed for digitization, the transmitter unit of the digitizer (see Fig. 3.5) must be moved from the chair to the transmitter holder table delivered with the system. The transmitter is released by sliding it off from its plastic holder. Under the table there is a similar plastic holder. Slide the transmitter to the holder and move the table under the headrest of the bed. The cable of the transmitter should point downwards (chair) or towards the feet of the patient (bed).

Refer to *Data acquisition User's Manual* for detailed digitization instructions.

If needed, additional points (e.g. electrode positions) can also be digitized.

NOTE! Large metallic objects, such as desks, cabinets, or the magnetically shielded room located near the transmitter or receivers of the 3D-digitizer may adversely affect the accuracy of the readings and thus the accuracy of source localization. Many walls, floors, and ceilings also contain significant amounts of metal.

To test whether the surroundings affects the accuracy of the readings digitize an object with known dimensions. For example, digitize the centers of the HPI coils permanently attached to the phantom and compare the readings with the known values (see Table 2 in section 7.2).

3.4. Recording

In both upright and supine measurement position make sure that prior to positioning the patient, the green 'OK' light of the position indicator display is lit. For details, see Section 5.2.

Guide the subject in the magnetically shielded room and assist him/her to the chair or on the bed. If seated measurement position is used follow the instructions given in section 5.5, in supine measurement position experiment follow the instructions given in section 5.4.

Plug the head position indicator coil connector to the HPI connector on the interface panel on the left side of the gantry (see Figs. 1.19. and 1.20) and the eventual electrode cap and reference and ground electrodes to corresponding connectors on the electrode interface panel (see Figs. 1.12. and 1.13) on the right side of the gantry.

NOTE! Instruct the patient to keep the head steady during the recording.

If a headbox is used, connect it into the appropriate connector (1–32 or 33–64) of the electrode interface panel. Connect eventual bipolar electrodes to the appropriate terminals of the electrode panel. Note that both reference and ground electrodes must be connected, either to the headbox or to the electrode interface panel.

CAUTION! Do not ground subject to actual ground (e.g. the wall of the magnetically shielded room). The GND terminal refers to isolated signal ground of the preamplifier, connected through a current-limiting driver circuit. Do not place conducting parts near the subject that he/she may touch while connected to the equipment.

The operator exits the room. Close the magnetically shielded room door.

NOTE! In case of studying patients or small children an accompanying person in the room is highly advisable, particularly if it is likely that the patient cannot call for help or get out in case of emergency. Audio and video monitoring is also recommended.

If an intercom system is installed ask the subject if the subject is ready. Start the data acquisition. For acquisition software release 3.3 and later an electrode impedance check window is displayed. Check the impedance levels and correct if necessary. For optimum performance, impedances below 10 kΩ are recommended. Measure the HPI coil locations with the respect to the sensor array. If the HPI fails, check the leads and ask the subject to move the head in a slightly different position and try again. Start stimulation if using any. During the acquisition, the raw data and averaged data should be constantly monitored, watching for any artefacts. Magnetic impurities left on the subject may cause severe artefacts; they should be removed. When enough data has been collected, stop acquisition and stimulation. Determine if additional recordings using, e.g. a different experimental condition, are necessary. Keep experimental log of recordings, stimulation conditions and trigger line assignments etc.

For details of the data acquisition software and on running the experiment, see *Data Acquisition Reference Manual.*

When the measurements have been finished, open the door of the magnetically shielded room. Disconnect the HPI coil set and electrodes or electrode caps from the corresponding connectors. Remove stimulator leads and actuators as needed.

If seated measurement position was used release the elevation mechanism of the chair and pull the chair from underneath the Dewar. In supine measurement position, release the lock of the upper bed and pull the upper bed away from the gantry. Support the subjects head if appropriate. Lock the upper bed again.

Help the patient to come out of the magnetically shielded room.

Remove the head position indicator coils and electrodes and clean them (see Chapter 8.7). The cap can normally be removed easily from subject's head. If it does not get loose easily, wet the cap and hair with a hand shower. Be careful not to get water into the 37-pin connectors. The paste and gel can be removed from the hair by ordinary shampoo and water.

4. Cryogenics

4.1. Precautions

CAUTION! As to potential hazards and necessary precautions for handling liquid and gaseous Helium, refer to Section 2.1 in addition to this Section. Before attempting to transfer liquid Helium read first that section and these instructions entirely.

When refilling the Dewar with liquid Helium one must be aware of and respect the following physical facts:

1. Liquid Helium is *very* cold and the latent heat of evaporation is very low. Therefore, Helium stays in liquid form only in specially designed vessels or transfer tubes. If the liquid gets in contact with objects at temperatures higher than 4 K it will immediately evaporate and expand. At room temperature the volume of the gas is 750 times larger than the liquid volume. This means that a potential for dangerous pressure rise always exists if this cryogenic liquid is handled carelessly or left to warm up in a completely closed volume.

2. At liquid Helium temperature all common materials are solid. This means that the vapor pressure of for example the atmospheric gases (nitrogen, oxygen, water) is practically zero in any volume containing liquid Helium which leads to *cryopumping* (see 2.1) of these gases: any Helium vessel left open to atmosphere will very effectively suck in large amounts of these gases. Water freezes and may block the Helium vessel or a transfer siphon. Oxygen in the probe unit Dewar causes large irregular low frequency drifts to MEG signals because oxygen in its solid form is very paramagnetic. Because of the above, all vessels containing liquid Helium must be sealed from the atmosphere and properly vented, via a back flow valve or a sufficiently long and narrow exhaust tube.

3. Flow of cold Helium gas makes a very good thermal contact with any surface it passes by: unprotected skin cools below freezing point in seconds.

4. Even after warming up to room temperature the odorless and colorless gas may cause a risk of suffocation if ventilation is not taken care of. Breathing Helium gas does not bring about any physiological unpleasent symptoms before dizziness. The pitch of the voice of the person characteristicaly raises when a large fraction of air is replaced with Helium gas.

You should avoid using magnetic tools and electrical equipment, like hot air guns inside the magnetically shielded room. If absolutely necessary, they must be kept more than one (1) meter away from the sensor array. For sensor detrapping, see 2.4.2.

4.2. Refill schedule

The recommended liquid Helium refill interval of Elekta Neuromag® is 7 days. It is recommended that a fixed weekly schedule is set up for Helium transfer. In addition to the person responsible for the transfer, backup personnel should be assigned.

It is highly advisable to monitor the Helium level regularly to avoid accidental warming up of the system. Should the level be very low, an extra refill should be performed. One should not, however, bypass the regular filling schedule even if additional refills are performed. After the Helium level has reached zero percent, there is still a reserve for about 24 hours left. However, system performance deteriorates if the Helium level is near or below zero percent. Therefore, a refill should be performed before proceeding to the next measurement. The system should not be left to warm up by itself; if this happens, re-evacuation of the vacuum space of the Dewar must be performed by authorized service personnel.

The Helium transfer takes about one hour. After the transfer, it is recommended to allow the temperature in the Dewar to stabilize for about an hour before starting new measurements and check the performance of the system as described in section 8.3.

4.3. Monitoring the Helium level

The real-time computer system takes a Helium-level reading approximately once in an hour. Readings are not taken during data acquisition.

The location of the He-level gauge is shown in Fig 4.1.

The Helium level log file can be studied with the "*Helium*" utility from the Maintenance folder or from Tools menu of the data acquisition program. You can view a graphical display of the Helium level and obtain an estimate of the time when zero-percent level is reached.

The Helium level can also be checked from the local Helium display in the magnetically shielded room. The Helium level probe is switched on and off by pressing the toggle button on the local display. The reading stabilizes in about 20 — 30 s. Each LED in the display corresponds to 1.6 percent.

NOTE! Remember to switch off the probe after taking a reading by pressing the toggle button again. If the probe is on, extra noise will appear and the boiloff will increase.

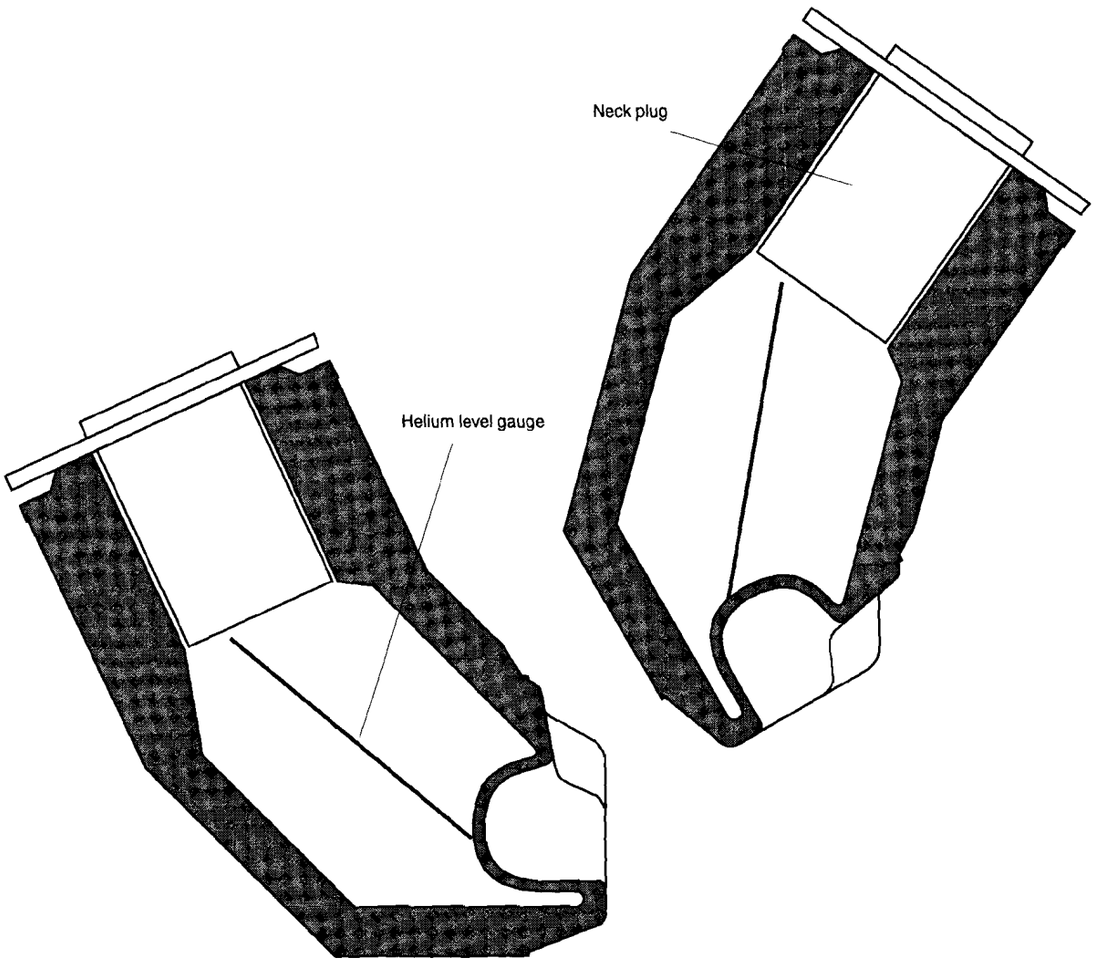


Figure 4.1. Location of the Helium level gauge.

The Helium level probe does not cover the whole Helium space. A zero reading in seated position corresponds to a level where all the sensors are barely immersed in liquid Helium while the 100-percent reading level in seated position the He-level is close to the lower edge of the neck plug. Refer to Table 1 for actual values in both seated and supine positions.

The normal boil-off rate is about 8 liters/day, corresponding to a transfer interval of one week. When the Helium probe reading is zero there is still about 13 liters of liquid in the helmet shaped part of the Dewar. A refill should, however, soon follow.

When you have checked the Helium level, estimate whether zero level is reached before the next scheduled refill. If this is the case schedule an extra refill.

The liquid Helium level and boiloff rate should be monitored regularly. Substantial increase of boiloff rate may indicate the need to re-evacuate the vacuum. The vacuum pump-out must be left to trained service personnel.

Table 1. Liquid Helium level data					
Liters	% (supine)	% (seated)	Liters	% (supine)	% (seated)
13	0	11	46	51	49
14	1	12	47	51	50
15	3	14	48	54	51
16	5	16	49	55	53
17	7	17	50	57	54
18	8	17	51	58	55
19	10	18	52	59	56
20	12	20	53	60	57
21	14	21	54	61	58
22	16	22	55	62	59
23	17	23	56	64	60
24	18	24	57	66	61
25	20	25	58	67	62
26	22	26	59	68	63
27	24	27	60	69	64
28	25	28	61	71	66
29	26	30	62	73	67
30	30	32	63	75	67
31	31	33	64	76	68
32	32	33	65	77	69
33	33	35	66	78	70
34	35	36	67	80	71
35	36	37	68	83	74
36	37	38	69	84	75
37	39	39	70	85	57
38	41	41	71	87	76
39	42	42	72	89	78
40	42	42	73	91	79
41	43	43	74	92	80
42	44	44	75	94	82
43	46	45	76	96	83
44	48	46	77	98	83
45	50	48	78	100	85

4.4. The Helium transfer procedure

Familiarize yourself with safety instructions before transferring Helium.

CAUTION! Wear protective gloves to avoid skin contact with liquid Helium or exhaust gas or any objects that have recently been in direct contact with liquid or evaporated gas. During transfer, monitor pressure gauges and do not let pressure to rise above limits described below.

1. If the exhaust line is equipped with an electrical Helium gas flow meter (outside of the MSR, not installed on all sites), bypass the meter by opening the bypass valve.

2. Record the Helium level and the gas volume gauge (if installed) reading to the Helium transfer data sheet or log.

3. Have at least 90 liters of liquid Helium available in a nonmagnetic storage container. Move the gantry to supine position.

4. Move the storage container to the magnetically shielded room entrance and connect the exhaust of the storage container to the transfer exhaust hose. The hose includes a rubber balloon pump and a plastic hose clamp valve, see Fig. 4.2. Close the hose clamp, then open the exhaust valve on the storage container and let the pressurizing unit balloon fill up. Then close the exhaust valve, open the hose clamp, and squeeze the balloon. Repeat this procedure 2–3 times, it will flush air out of the transfer hose and balloon. Close the hose clamp and the safety relief valve of the storage container.

5. Clean your hands. Check that the filter unit at the tip of the thin, stiff part of the transfer siphon is in place. The siphon extension tube can be used if needed. The extension tube is mounted between the filter unit and the vertical part of the siphon.

6. Check that the Helium exhaust line is unobstructed.

7. Lower the transfer siphon slowly into the storage container. Helium gas should be let flow through the siphon in order to get air out of it. Now open the hose clamp and temporarily plug the open end of the transfer siphon with a short silicon hose (12 mm) having a knot on it. Lower the siphon **slowly** to the bottom.

8. Move the storage container into the magnetically shielded room. If you have a long siphon (can be ordered separately) the storage container can

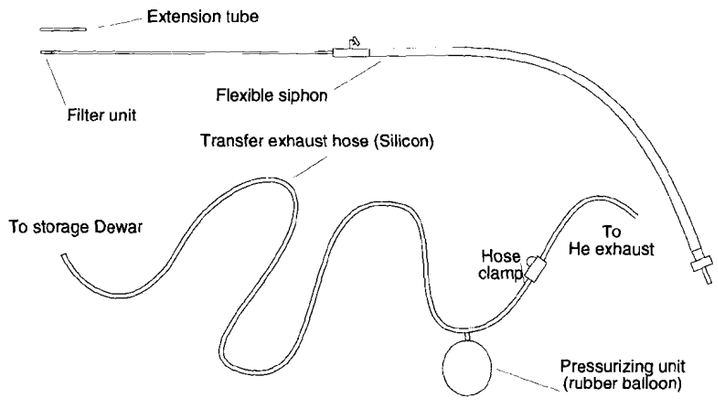


Figure 4.3. Parts needed in liquid Helium transfer.

be left outside of the room. Open the right side cover of the gantry and open the precooling valve on the side panel. Remove the knotted silicon hose and fasten the siphon end to the precooling socket. Act rapidly to minimize the possibility of air getting into the probe unit. Tighten the knurled sleeve nut slightly at the siphon. If the tip of the siphon does not slide easily to the precooling holder, apply a small amount of vacuum grease to the O ring. If you have a long siphon with the storage container outside of the room, ground the braided cover of the siphon to the magnetically shielded room wall and support the long flexible tube at least at one point; the exact realization of such arrangements is site-dependent.

9. Block the transfer exhaust hose with the plastic hose clamp valve. Close the relief valve of the storage container. Squeeze the rubber balloon gently. Helium flow through the precooling hose starts. Follow the pressure indicated by the gauge on top of the probe unit of the Elekta Neuromag®; **the pressure should stay lower than 0.1 bar** (10 kPa). If necessary, you can lower the pressure by letting gas out of the storage container through the transfer exhaust hose.

10. In a few minutes the siphon cools down sufficiently. This is indicated by heavy frost on the precooling line on the gantry. Release the plastic hose clamp valve and wait for the pressure to go down.

11. Use thick protective gloves and beware of the cold Helium flowing out. Close the valve on the precooling socket. Loosen the knurled sleeve nut holding the siphon in place. Leave the siphon in the precooling socket. Loosen the plug at the input of the siphon fixed to the probe unit of the Elekta Neuromag®. Replace the plug **as quickly as possible** with the tip of the siphon. During the short interval when the fixed siphon on the probe unit is unplugged there should be Helium flowing out of the fixed siphon as well as from the flexible siphon. If this is not the case there might be a plug of frozen air in the siphon, see Section 4.5. Secure the siphon in place by tightening the knurled sleeve nut on the siphon. Place the plug of the fixed siphon to a place where it is readily available, e.g., the plug holder at the cover of the refill opening or the precooling socket.

12. Block the transfer balloon exhaust hose with the plastic clamp again and pump gently with the rubber balloon. Follow the pressure from the probe unit of the Elekta Neuromag® gauge; do not let the pressure rise over 0.1 bar (10 kPa). The pressure rises quickly at first. When the flow of liquid starts after a few minutes the pressure goes down for a moment and then rises again to approximately 0.04 — 0.07 bar (4–7 kPa) depending on the flow impedance of the exhaust line. After the liquid starts flowing you can usually pump the balloon continuously until the transfer is complete. When the desired Helium level is reached, release the transfer exhaust hose clamp valve and let the pressure stabilize for a couple of minutes.

13. Detach the siphon from the probe unit when the pressure has decreased. Have the plug ready. Pull the tip of the siphon out and insert the plug as

quickly as possible. Tighten the plug. Move the storage container out of the shielded room and lift the siphon out. Use gloves to avoid frost bite. Close the exhaust valve on the storage container. Disconnect the transfer hose and open the relief valve on the storage container.

14. Record the time of transfer, amount transferred, and the reading of the gas volume gauge (if installed) to the Helium transfer data sheet. Close the bypass valve (if installed) of the electrical gas flow meter.

14. Return the storage container to its place.

NOTE! After finishing transfer, check that all valves are in their normal positions, that is, vessels containing liquid helium are vented through their proper return lines and all the other valves are closed. Remember to switch off the local liquid Helium level display.

NOTE! In installations where the siphon precooling line has been left out, let He exhaust first into the atmosphere through the flexible siphon. Then connect the tip of the flexible siphon to the fixed siphon as in 11 above and continue slowly as in 12. Adequate ventilation of magnetically shielded room must be provided, cf. Sect 2.1.2 and 4.1.

4.5. Troubleshooting transfer problems

Use caution and care when handling the Helium storage containers. One liter of liquid Helium corresponds to approximately 750 liters of NTP (Normal Temperature and Pressure) Helium gas. Cold Helium may cause frost bites and it may replace breathing air. However, there is no need to be alarmed when liquid Helium is properly handled.

CAUTION! Beware of the extremely cold, non-life-supporting gas.

The following hints may help you in solving problems which may arise during a transfer:

- The pressure in the probe unit of the Elekta Neuromag® goes high.

  Release the hose clamp valve blocking the transfer exhaust hose. If the pressure still keeps increasing, open the relief valve on the storage container and the siphon precooling valve. **Watch out for the eventual stream of extremely cold gas.**

  The relief valve of the probe unit will open when the pressure inside the Dewar is 10 kPa (0.1 bar). If the pressure goes up further to approximately 60 kPa (0.6 bar), the safety rupture membrane on the top plate breaks and Helium gas will flow though the emergency duct. Should this happen or if the membrane breaks by itself, plug the membrane opening with a rubber bung contained in the Cryogenic Accessory Kit after the pressure has decreased. Try to identify the cause of the pressure rise, and have the safety rupturing membrane replaced.

- The frozen silicon exhaust hose of the probe unit breaks because of thermal stresses.

  This may be associated with a loud popping sound and a greyish cloud of gas caused by condensing moisture. This may sound and look dramatic but **do not panic.**

  Should this happen, open the hose clamp valve at the transfer exhaust hose of the storage container and let the pressure drop. **Beware of the extremely cold, non-life-supporting gas.**

  You may wish to step out of the magnetically shielded room while waiting for the pressure to drop. Replace the broken silicon hose when it has warmed up sufficiently. There is a spare hose and plastic connection pieces in the Cryogenic Accessory Kit provided with the system.

- There is not enough Helium to complete the transfer.

  This shows up as difficulties in maintaining the pressure in the storage container, and the local level indicator also stops rising. If the transfer is far from complete get a new storage container and start again. Dry the inside of the flexible siphon when necessary, for example, by blowing warm gas through the siphon. If you leave the transfer incomplete ensure that the transfer schedule is modified accordingly.

- There is no flow of liquid and the pressure in the storage container does not go down even if pumping is stopped.

  This may be caused by frozen air or moisture obstructing one or both of the siphons.

  Stop transfer, depressurize the storage container, remove the flexible siphon, observe the outflow of Helium, and plug the fixed siphon. Some Helium should emerge out of the fixed siphon head. If no Helium flow appears at the end of the flexible siphon even if the storage container is slightly pressurized, there is a plug in the flexible siphon.

  If the air plug is in the flexible siphon, stop transfer, warm the siphon up, let it dry and start again. If there is no Helium flowing out from the fixed L-siphon mounted to the probe unit of the Elekta Neuromag® when the plug is removed, the frozen air or moisture plug is within the fixed siphon. Call an Elekta service representative.

- There is excessive flow of Helium gas but no liquid is transferred and the siphon (flexible or fixed) feels cold.

  The insulating vacuum of the siphon is bad, and it needs to be re-evacuated by service personnel. Use another siphon if available.

- Transfer does not succeed and the lower tip of the Dewar feels cold.

  This may happen due to poor insulating vacuum. The vacuum has to be re-evacuated, which is a normal procedure during annual maintenance. Call an Elekta service representative.

5. Gantry, bed, and chair

5.1. Construction

The constructions of the gantry, bed, and chair are shown in Fig. 5.1. The gantry comprises the base unit and the probe unit which is inside the rotating cradle. The helmet shaped lower tip of the Dewar extends outside the cradle. The gantry has two fixed, predefined, tilt angles corresponding to supine and upright measurement positions. Either of the measurement positions can be chosen by using the up- or down-buttons and the manual latch release bar that are on the rear side of the gantry.

CAUTION! Change of the measurement position must not be done when a patient or the chair is underneath the gantry.

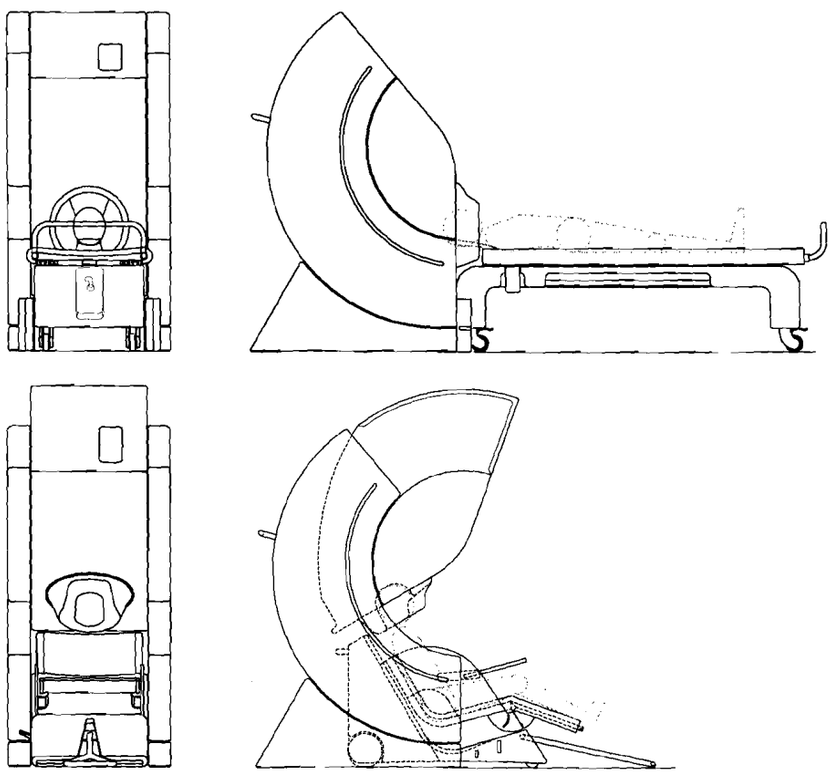


Figure 5.1. Upper picture: Supine measurement position. Lower picture: Upright measurement position.

On both sides of the gantry there are covers under which EEG and auxiliary electronics interfaces are located. The covers are opened and closed from the front of the gantry.

The patient bed is mobile and its wheels are provided with locks. The gantry is equipped with a removable bed docking piece that is used together with the patient bed. After docking the bed to the gantry and locking the wheels the lock of the upper bed can be released and the upper bed can be moved in horizontal direction.

The patient chair is provided with wheels. The green handle can be used to position the chair underneath the Dewar. After adjusting the position of the chair an elevation pedal on the side of the chair is pumped to elevate the seat. The seat can be lowered by pushing the release pedal down.

CAUTION! Care should be excercised to prevent limbs being left between moving parts of the chair or bed and gantry or doorway.

5.2. Position indicator display

The operation of the gantry lifting mechanism can be monitored with the help of the position indicator display located on the wall behind the gantry, see Fig. 5.2.

Indicators of the display are the following:

Green light "OK": Gantry position is secured (supine or seated). This is normal position. Never place a subject under the gantry except when green "OK" light is lit.

Amber light "Tension": Gantry position is not secured, and weight of the dewar cradle tensions the ropes of the lifting mechanism. This is normal during up/down movement. When tension of the ropes is released (and light goes off), downward movement of the motor stops.

Amber light "Limit": Dewar cradle has reached the upper limit of the upward movement and motor stops. Only downward movement is possible. This is normal during up/down movement.

Red light "Fault": Abnormal condition due to malfunctioning of the lifting mechanism and/or the fiber optic sensors monitoring the position. Contact service representative.

CAUTION! Do not place the patient under the gantry except when the green "OK" light is lit.

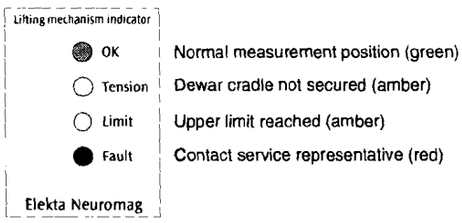


Figure 5.2. Position indicator display unit.

5.3. Changing the position of the Dewar

CAUTION! Do not engage the lifting mechanism if the patient is underneath the gantry.

The dewar can be set to two fixed positions: Up for seated upright position studies with the chair and down for supine position studies with the bed. The measurement array inside the helmet shaped lower part of the probe unit is tilted from vertical by 30° in the upper position and horizontal in the lower position.

5.3.1. Changing the position from supine position to upright position:

- Remove the bed and bed docking piece from the base unit and make sure that no one is underneath the dewar during position change.
- Press the up-button located in the back of the gantry (see Fig. 5.3). The dewar starts moving up. On the position indicator display the green "OK" light goes off and the amber "Tension" indicator lights up. Near the uppermost position, you will hear the latches to lock. Keep on pressing the up-button until the dewar has rotated into the uppermost position and the movement stops. This is also indicated by the amber "Limit" light. Do not stop the movement unnecessarily by releasing the up-button.

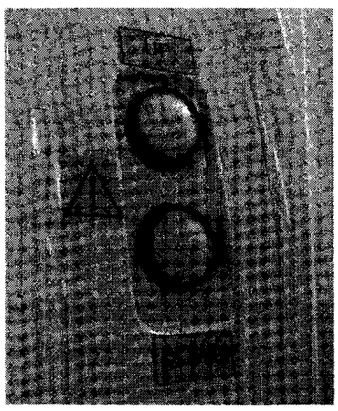


Figure 5.3. Lifting mechanism control buttons

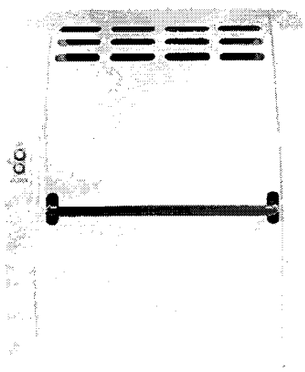


Figure 5.4. The latch release bar

- Press the down-button until the dewar stops over the latches. The movement is very short. Now the weight of the dewar is carried by two locking latches. A green "OK" light on position indicator is led to show that the system is ready for use. All other lights on the indicator display should be off.
- Wait a few minutes for stabilization before starting measurements.

5.3.2. Changing the position from upright position to supine position:

- Remove the chair from the gantry and make sure that no one is underneath the dewar during position change.
- Press the up-button located in the back cover of the gantry until the movement of the dewar stops and the amber "Limit" light is lit. The "Tension" indicator is also on but "OK" indicator is off. The movement is very short.
- Grab the greenlatch release bar on the back of the gantry (see Fig. 5.4) and pull it down. This will disable the locking latches of the dewar. Press the down-button and keep it pressed while you keep the bar down. After the dewar has rotated downwards and passed the latch position you can release your hand from the bar without releasing your other hand from the down-button.
- Continue pressing the down-button until the dewar has rotated to the supine position and the movement stops. A green "OK" light on position indicator is lit to show that the system is ready for use. All other indicator lights should be off. Do not stop the movement unnecessarily by releasing the button.
- Insert the bed docking piece to the base unit of the gantry.
- Wait a few minutes for stabilization before starting measurement.

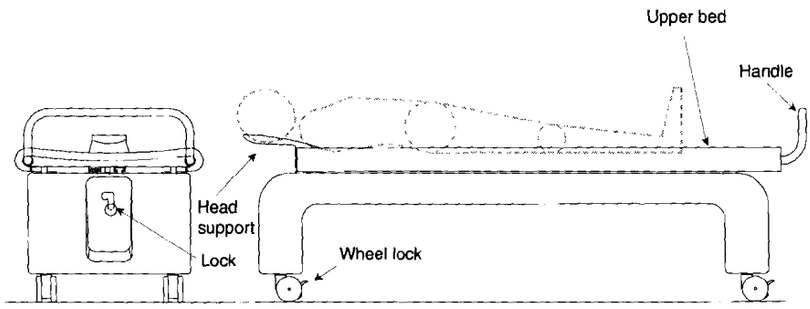


Figure 5.5. Construction of the patient bed

5.4. Positioning the patient in supine position

Construction of the bed is shown in Fig 5.5. It has wheels and a movable upper bed; both the wheels and the upper bed can be locked. With the locks of the wheels open and the upper bed locked, the patient bed can be moved in and out of and inside the magnetically shielded room. The easiest way to move the bed is by pushing/pulling it from the green handle which is located in the rear end of the upper patient bed. After docking the bed into the gantry, lock the wheels of the bed.

If the head support is used, unlock the upper bed on which the patient is lying and push it towards the gantry until the patient's head is covered by the helmet. Then lock the upper bed. During the measurement, the patient's head leans against the head support. After the measurement, the upper bed unlocked and is pulled off the gantry. Lock the upper bed again.

Alternatively, when head support is not used, the bed is first pushed against the gantry with patient's head on bed and docked. Only after that the patient's head is slid into the helmet. During the measurement, the patient's head leans against the Dewar helmet. After the measurement the patient's upper part of the body is first pulled out of the helmet and the head supported onto the bed.

If the bed is moved after the measurement, release the locks of the wheels. Move the bed using the green handle.

5.5. Positioning the patient in seated position

5.5.1. Construction of the chair

Construction of the chair is shown in Fig. 5.6. The height of the seat of the chair is adjusted using the pedals which are on the side of the chair: To elevate the seat pump the elevation pedal which is on frontal part of

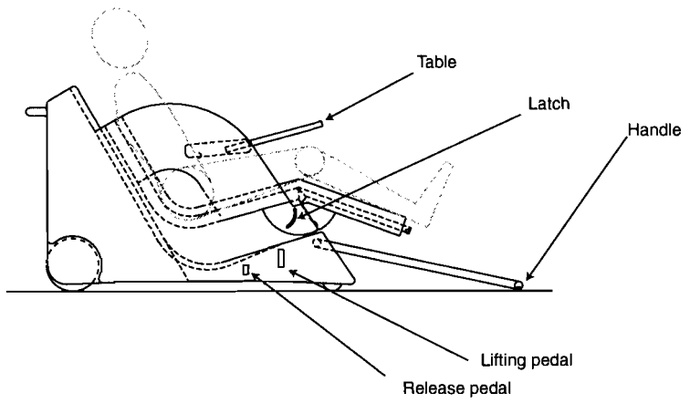


Figure 5.6. Construction of the chair

the side; to slide the seat downwards push constantly the release pedal on the rear part of the side.

NOTE! Do not use force or stand on the elevation pedal after the maximum height of the seat is reached. The pedal might break.

The chair can be moved using the green handle. The handle locks into its uppermost position. A break that prevents the chair from moving is activated when the handle is lowered against the floor.

The lower parts of leg rests can be elevated to nearly horizontal position. Elevate the legrest by hand or foot to the upmost position. The leg rests will lock automatically and will be released when lifted again.

A dedicated table is part of the system delivery. Attach the table by gliding it in the guides on the side panels of the chair.

A pillow set is delivered with the chair. Use the pillows, as needed, behind the subject's lower back or shoulders.

The chair is equipped with a safety belt that can be useful in stabilizing the subject and preventing the subject from drifting down during the measurement.

5.5.2. Subject preparations and positioning

Refer to Section 3.3 for patient preparation. Adjust the Dewar to the upright position as described in Section 5.3.

Before placing a patient into the chair elevate the upper part of it to half of the maximum height. Now it is easy for the patient to sit down into the chair. For patients with limited movement capacity it is advisable to have the chair in the uppermost position. For tall patients use also the shoulder support pillow. Adjust the lower back support pillow as needed. Fasten the seat belt firmly over the hipbone for increased stability. Insert the dedicated table into its guides according to the need.

CAUTION! Be careful not to get fingers or toes between moving parts. Instruct the patient to keep hands on the table or armrests.

When the patient is sitting in the chair the seat is lowered down by pushing down constantly on the release pedal. The chair can then be pushed underneath the Dewar using the green handle of the chair. Be careful when approaching the helmet, tall patients may have to bow their head. Push the chair first all the way in.

Lock the chair temporarily (before final adjustment) in place by lowering the handlebar to the lowest position close to the floor. The seat is then elevated by pumping on the front pedal on the right hand side of the chair until the patient's head is covered with the helmet. Keep lifting until the top of the patient's head touches the top of the helmet. Inform the patient to give feedback during lifting. During the measurement the subject/ patient's head leans against the Dewar helmet.

The lower parts of leg rests can be elevated to nearly horizontal position. Grab the leg rest with one hand and elevate it to the upmost position. The rests will lock automatically and will be released when lifted again. After the measurement, release the leg rest by slightly elevating it which releases the latch. Support the leg rest when lowering it down.

Advise the patient to lean back on the helmet and relax. Adjust the position of the chair in the front-back direction as needed to maximize patient's comfort. Use additional pillows from the pillow set provided with the chair. Comfortable position minimizes patient fatigue and head movement.

After the measurement lower the chair by pushing down on the release pedal, backmost on the right hand side of the chair. Remove table/ handrest, lower the footrests and advise the patient, minding his/her head, to rise from the chair or pull the the chair out and help the patient up.

Note! Advise the subject/patient to keep his/her hands in the lap or on the dedicated table during the lifting or lowering to prevent limbs being left between moving parts. The side plates of the chair also protect the subject's/patient's arms.

5.6. Getting the patient out in case of emergency

NOTE! In both supine and upright positions the EEG- and HPI-cable connectors ought to be disconnected prior to moving the patient if possible.

NOTE! In the supine measurement mode when head support is used release the lock of the upper bed and then pull the upper bed outwards. In some device models it is possible, using some extra force, to pull the upper bed outwards from the measurement unit without releasing the locks.

If the head support of the upper bed is not used, pull first the patient's upper body so that the patient's head is out of the helmet on the bed. Release the lock if applicable.

In the upright measurement mode one should first lower the seat of the chair by pushing down constantly the release pedal and then by pulling the chair from underneath the helmet using the green handle.

6. Electronics

6.1. Precautions

CAUTION! For precautions concerning electrical safety and artefact-free operation refer to chapter 2.2.

NOTE! The electronics contains components susceptible to static electricity. Read precautions of chapter 2.6.2 first.

6.2. General

6.2.1. Rack installation

CAUTION! The electronics is designed to be operated in proper RF-shielded cabinet mounting only. Do not disconnect any cables. In particular, the unit must be operated with cooling fan units on. Their cables must not be disconnected.

The main electronics cabinet comprises two MEG subracks, one EEG subracks and an MEG preamplifier power supply. The mounting of the units inside the cabinets is shown schematically in Fig. 6.1.

6.2.2. Electronics control

Normal operation of the electronics requires no user action except power-up and shutdown. All settings of the electronics are computer controlled. Pre-defined settings for proper SQUID working points are automatically loaded to electronics at power-up. For further details, refer to *Sensor Tuner User's Guide* and *Data Acquisition User's Guide.*

6.2.3 Power supplies

CAUTION! There are no operator serviceable parts inside the power supply units. Do not open the covers.

The main electronics subracks have several power supply units.

6.2.4. Isolated EEG Power Supply

Isolated power supply for EEG amplifiers is located in the feedthrough unit. It is powered by a 24V~ transformer in the preamplifier power supply unit inside the main electronics cabinet.

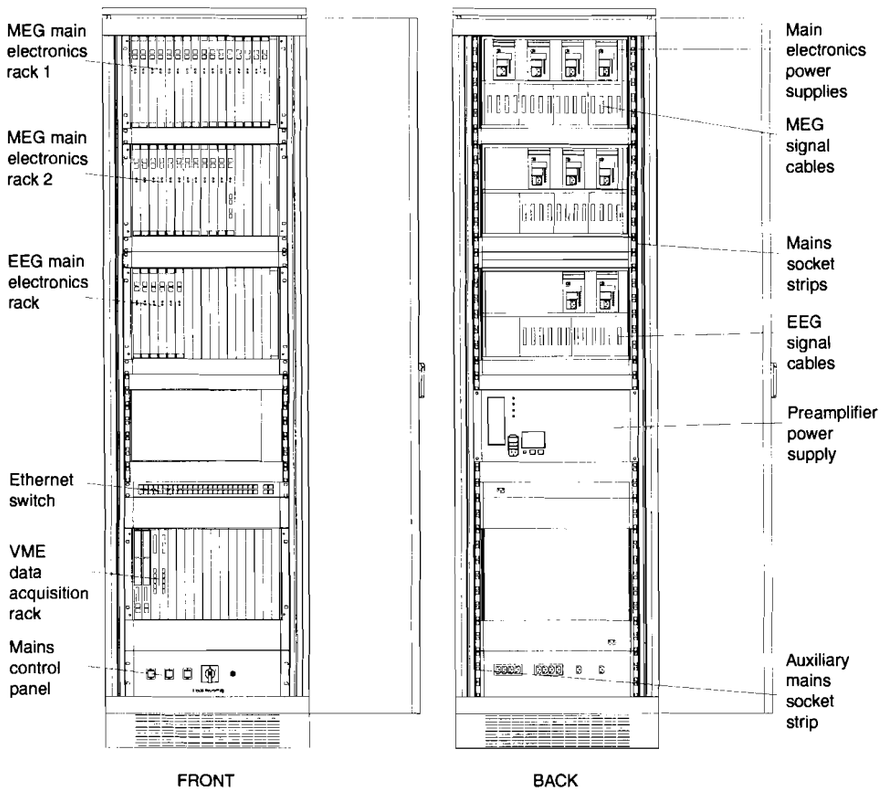


Figure 6.1. Mounting of the electronics units inside the main electronics cabinet. Left: front view, right: back view.

6.3. Powerup and shutdown instructions

6.3.1. Cold start powerup after mains failure

NOTE! The main electronics cabinet has been equipped with a power failure release main switch to ensure proper boot-up sequence of the computers. Please follow these instructions after the mains power coming to the main electronics cabinet has been off due to mains failure or because of disconnecting the power from the isolation transformer for e.g. service operations.

1. Boot the acquisition workstation if it has not started automatically. Wait until it runs normally.

2. On the mains control panel of the main electronics cabinet (see Fig. 6.2), ensure that the green rocker switches (Preamplifiers, real-time computers, main electronics) are in "off" position.

3. Inside the MEG electronics cabinet, the individual power supply units are connected to outlet socket strips located in the reare of the cabinets. Ensure that the power cords are in place and that the switches of the individual power supplies are in the "on" position.

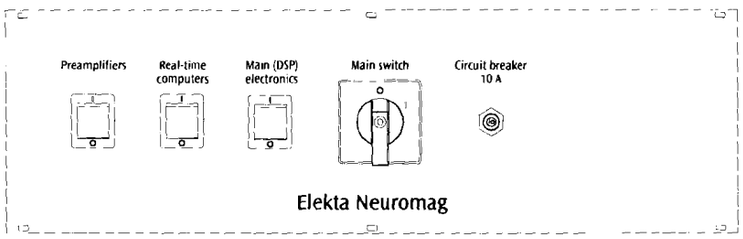


Figure 6.2. The mains control panel of the main electronics cabinet.

4. Switch on the main electronics cabinet power by turning the main switch on the mains control panel. The switch will automatically turn back into "off" position if mains voltage is too low.

5. Proceed with normal powerup instructions (6.3.2).

6.3.2. Normal powerup

1. Make sure that the main main switch om the mains control panel is in the "1" position.

2. After turning the main switch to "1" position, wait until the ethernet switch has started up, indicated by the "self test" and "fail" indicators going off. Bootup takes about one minute.

3. Switch on the real-time computers from the mains control panel.

4. Switch on the Main (DSP) electronics from the mains control panel. Wait until all electronics boards show steady green "run" lights and the "fail" lights are off. Boot-up takes about 30–60 seconds. If the bootup fails, open the back door of the main electronics cabinet and check the indicator LEDs of individual power supplies (see Fig. 6.3).

5. Switch on the Preamplifiers from the mains control panel.

6. Run Restart acquisition programs by double-clicking its icon in the Maintenance toolbox on the acquisition workstation

NOTE! Each time the MEG front end is powered it must be initialized, either by invoking the restart acquisition programs as above or by invoking the Squiddler utility program and issuing the initialize electronics command **immediately** after all voltages are on. Failing to do the initialization can lead to increased liquid helium boiloff rate resulting in substantially shortened refill interval.

NOTE! For optimum noise performance, let the preamplifiers stabilize for approximately two hours before commencing MEG measurements. Keep the preamplifier power supply normally always on.

NOTE! individual main electronics power supply units will not start up if any of their indicator LEDs on the back (see Fig. 6.3) is lit. This may happen if a powerup is made immediately following power-down of the unit.

6.3.3. Power shutdown

Before *any* electronics service operations, main power must be switched off.

1. Switch off Preamplifiers, Real-time Computers and Main (DSP) electronics from the mains control panel.
2. Switch off the main switch on the mains control panel. This will turn off the ethernet switch, the roof fans and eventual equipment connected to the auxiliary sockets, e.g. the optional intercom.

NOTE! It may take a while before the LED indicators go off. A main electronic power supply unit will not restart before all indicators are off.

After service operations, follow the start-up instructions given above.

6.4. Protection

6.4.1. Fuses

CAUTION! To avoid risk of fire and of electric shock use only correct-rated fuses as replacement.

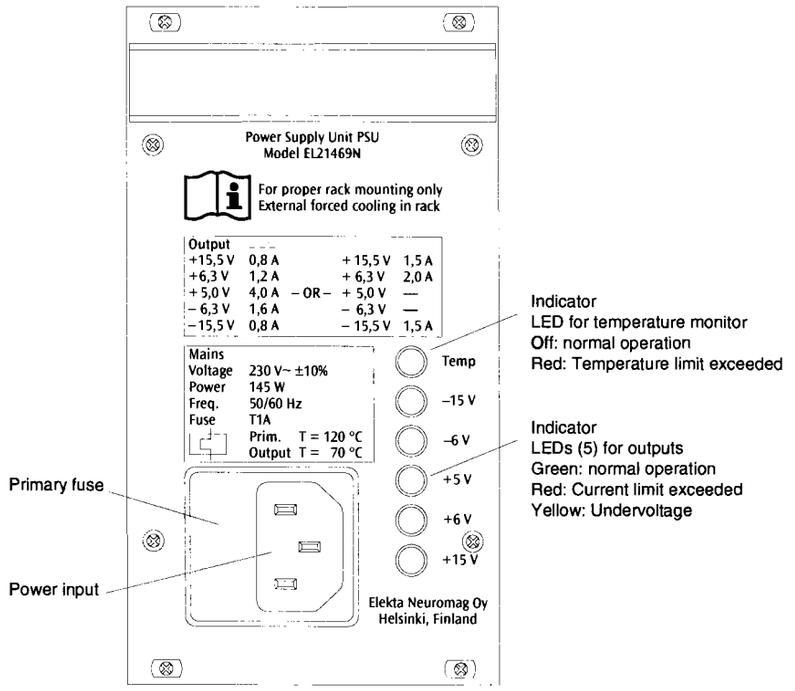


Figure 6.3. Back panel of a main electronic power supply unit.

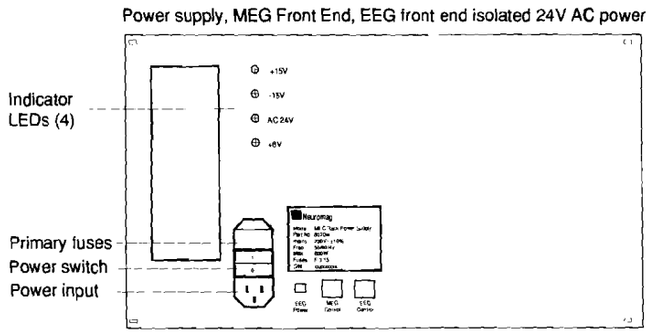


Figure 6.4. Back panel of the preamplifier power supply unit.

All mains (primary) circuits of the power supply units are fused. All fuses are accessible at the back planes of the power supply units with the correct values of the fuses marked in the immediate vicinity, for details see Figs. 6.3 and 6.4. A "T" before the rated current in amperes indicates slow (time-lag) type and an "F" fast type. If no type has been indicated, use fast type fuses. Main electronic power supply units have a spare fuse in the fuse holder.

6.4.2. Limiting circuits

The main elecronics power supply units and the preamplifier power supply unit have fuses and/or current-limiting circuits on the low-voltage side.

NOTE! If any output current of a main electronics power supply unit exceeds its limit, the unit will turn off all its output voltages, and the indicator LED for that voltage will turn red.

If a current-limit shutdown occurs, try restarting the unit by detaching its power cord, wait unit the red indicator LED goes off and re-connect the power cord. During startup, all indicators are lit briefly in a sequence first green and then red. If the problem persists or repeats often, call a service representative.

6.4.3. Undervoltage detection

The main elecronics power supply units have undervoltage detection circuits on the low-voltage side.

NOTE! If any output voltage of a main electronics power supply unit falls below its limit, the unit will turn off all its output voltages, and the indicator LED for that voltage will turn yellow.

If an undervoltage shutdown occurs, try restarting the unit by detaching its power cord, wait unit the red indicator LED goes off and re-connect the power cord. During startup, all indicators are lit briefly in a sequence green and red. If the problem persists or repeats often, call a service representative or have the mains supply voltage checked by a electrician.

6.4.4. Overtemperature protection

The main electronics power supply units and the Real-time computer VME rack have temperature protection circuits with over-temperature indicators. The VME rack indicator is on the front of the rack.

NOTE! The power supply units of the main electronics have two temperature-protection mechanisms. If the temperature of the power supply unit transformer exceeds the limit (primary) marked on the cover, a thermal switch will shut off the mains supply to the unit and all indicators will be dark. If the internal temperature of the low-voltage side exceeds the limit marked on the cover (secondary), the unit will turn off all its output voltages, and the indicator LED for the temperature will turn red.

If a secondary thermal shutdown occurs, wait at least 30 minutes to cool down the unit. Check that the fans operate normally. Try restarting the unit by detaching its power cord, wait unit the red indicator LED goes off and re-connect the power cord. During startup, all indicators are lit briefly in a sequence first green and then red. If the problem persists or repeats often, call a service representative.

If the transformer primary thermal shutdown occurs, disconnect the power cord of the unit and wait at least 30 minutes to cool down the unit. The primary winding thermal switch will reset automatically. Try restarting the unit by reconnecting its power cord. If the problem repeats, call a service representative.

CAUTION! Overheating is normally a symptom of a fault. To reduce risk of fire the reason must be resolved.

6.5. Cooling fans

The cooling airflow in the cabinet enters through a dust filter below the cabinet floor and exits throgh the top of the cabinet. In addition, there are individual local fan units, connected to mains supply so that they operate simlutaneuosly with the unit they are cooling. Power cords of these fan units must not be removed or replaced.

NOTE! For proper airflow in the cabinet, keep the doors closed. This also helps to reduce the acoustic noise from the fans.

The roof fans operate always when the cabinet main switch is on. Their speed is temperature-controlled to reduce acoustic noise. Do not alter the temperature setting.

6.6. Resetting the electronics

Each main electronics board (MEG and EEG) has a recessed reset switch on its front panel. If the board becomes locked up (e.g. showing red fail light or it stops responding to commands) press reset switch. Boot-up of the boards starts automatically. Wait until the board shows steady green "run" lights and the "fail" lights are off. Boot-up takes about 30–60 seconds. If the bootup fails, open the back door of the main electronics cabinet and check the indicator LEDs of individual power supplies (see Fig. 6.3).

If several boards fail simultaneously, all boards can be reset simultaneously by pressing the reset switch of the System Controller Board (SCC) which is located on the rightmost slot of the second MEG rack.

After resetting the boards, run "Restart acquisition programs" by double-clicking its icon in the Maintenance toolbox on the acquisition workstation.

7

7. Auxiliary electronics

7.1 Interface to stimulus electronics

7.1.1. Introduction

The stimulus I/O system is used to synchronize external stimulators and MEG signal averaging.

Two modes of synchronization are possible:

- *Internal triggering*: Averaging is triggered using pulses generated internally by the Elekta Neuromag® data acquisition hardware; these pulses are output via the stimulus I/O units for triggering external stimulators
- *External triggering*: External stimulators are used in a self-paced mode, and the stimulus synchronization pulses are input via the stimulus I/O units to data acquisition system hardware.

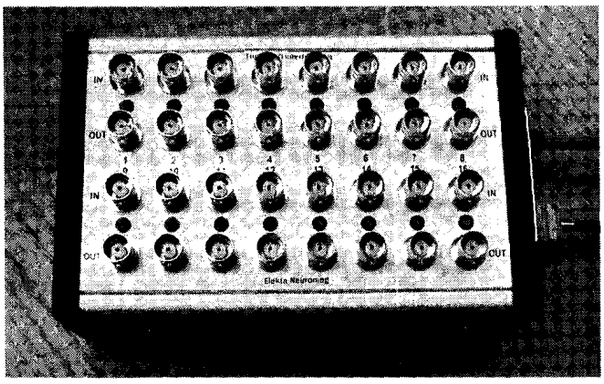
The stimulus I/O system has two interface units connected to the main electronics over optical fibre links. The trigger I/O interface boxes are placed near the stimulators.

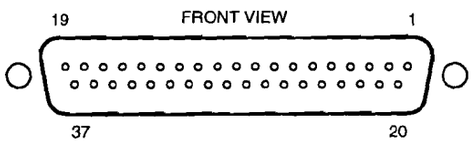
Each of the trigger I/O interface boxes has 16 lines, individually configurable as inputs or outputs. Stimulators can be connected using individual BNC connectors or a parallel 37-pin multipole connector.

NOTE! The BNC connectors and the parallel multipole connector are internally connected together. Do not connect the parallel connector simultaneously with the BNC connectors.

The two interface boxes can be operated in two modes which can be set from the data acquisiton software.

- mirror mode duplicates the signals on the first unit on the second unit which may at a physically separate place, making a total of 16 trigger lines. This mode, which is the default, may be useful in complex stimulus setups where stimulus-generating equipment may be located at distinct places.
- optional independent mode provides parallel operation of the units, making a total of 32 trigger lines. However, internal trigger pulse generation is only supporting 16 lines. The optional independent mode is taken into use from Data Acquisition Program. For details, refer to *Data Acquisition User's Manual.*





1: Input 1	10: Input 10	20: Output 1	29: Output 10
2: Input 2	11: Input 11	21: Output 2	30: Output 11
3: Input 3	12: Input 12	22: Output 3	31: Output 12
4: Input 4	13: Input 13	23: Output 4	32: Output 13
5: Input 5	14: Input 14	24: Output 5	33: Output 14
6: Input 6	15: Input 15	25: Output 6	34: Output 15
7: Input 7	16: Input 16	26: Output 7	35: Output 16
8: Input 8	17: Ground	27: Output 8	36: Ground
9: Input 9	18: Ground	28: Output 9	37: Ground

Figure 7.1. The stimulus trigger interface unit. Below, pinout of the parallel multipole 37-pin connector

7.1.2. Instructions for use

CAUTION! If any of the equipment connected to the the stimulus trigger interface unit is patient-connected, all other equipment connected to the same interface unit must fulfill the safety requirements of IEC 60601-1 for medical electrical equipment.

Verify correct voltage and polarity and connect the power supply to the DC connector on the side of the interface box (see Fig. 7.1.). Connect the optic link between the interface box and the main electronics cabinet. The green lights "Power" and "Link" on the unit should be lit.

For using internal triggering, select a stimulus channel and connect a BNC cable (not supplied) to the appropriate stimulator trigger output BNC connector of the stimulus I/O interface unit and to the stimulator trig-in connector. In the data acquisition program, select internal triggering and set the trigger channel, and interstimulus interval. Refer to the *Data Acquisition Reference Manual.* If you are using several stimulators, repeat the above steps as many times as necessary.

Correspondingly, for using external triggering, select a stimulus channel and connect a BNC cable (not supplied) between the appropriate stimulator trigger input BNC connector of the stimulus I/O interface unit and the stimulator trig out connector. In the data acquisition program, select external triggering and set the trigger channel. Refer to *Data Acquisition User's Manual.* If you are using several stimulators, repeat the above steps as many times as necessary.

In both cases, the LEDs in the interface box will be lit when a trigger pulse is input or output.

The input channels are factory set to trigger on rising edge of TTL-level pulses. Select the polarity of a particular channel from the corresponding "Input polarity" switch (located on the longer side of the unit). The inputs can also be used with passive switches. Therefore, an internal pull-up resistor is supplied. It is selected by sliding the corresponding "Input Pull-up" switch to "on". Normally, the input polarity should also be changed to falling edge if pull-up is used. The polarity of the output pulses can also be selected by from the corresponding "Output polarity" switch.

For specifications of the trigger input/output signals, see *Elekta Neuromag® System Hardware Technical Manual.*

The stimulus cabinet is available for placing various stimulator devices, providing isolated power and RF-filtered feedthroughs. The feedthroughs are specified and explained in greater detail in *Elekta Neuromag® System Hardware Technical Manual.* Active digital circuitry, e.g., a computer inside the stimulus cabinet should be avoided.

7.2. Phantom

A phantom is provided for checking the system performance. It contains 32 artificial dipoles and four fixed head-position-indicator coils. The phantom is based on the mathematical fact that an equilateral triangular line current produces equivalent magnetic field distribution to that of a tangential current dipole in a spherical conductor, provided that the vertex of the triangle and the origin of the conducting sphere coincide. The phantom dipoles are energized using an internal signal generator which also feeds the HPI coils. An external multiplexer box is used to connect the signal to the individual dipoles. Only one dipole can be activated at a time.

The phantom is shown in Fig. 7.2, and the locations of the dipoles are given in Table 2. The radius of the hemispherical plastic cover is 87.5 mm.

The fixed head position coils can also be used in checking the operation of the 3D-digitizing unit.

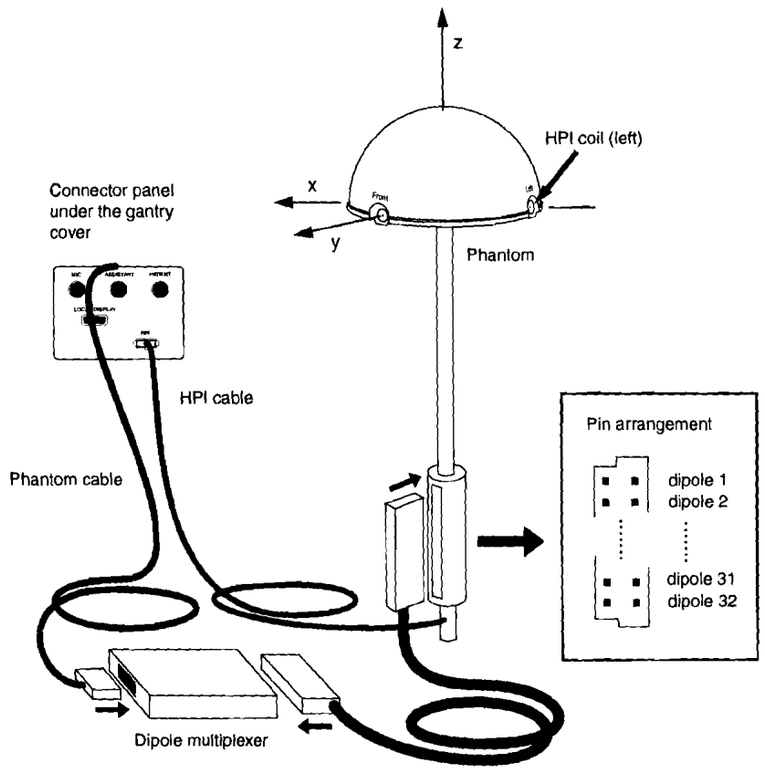


Figure 7.2. The phantom.

A phantom measurement is basically similar to an ordinary evoked-response measurement with HPI coil digitization etc. This is to check the accuracy of the whole measurement chain, comprising HPI coil digitization, data acquisition, and dipole source analysis.

For details of the measurement procedure, refer to *Data Acquisition User's Manual.*

1. Connect the phantom excitation multiplexer into the cable with a 25-pin connector which is under the side cover of the gantry.

2. Start the acquisition program. Select or create a project suitable for phantom measurement. Load the required measurement settings from a template file: Pick "Load measurement settings" from the "File" menu and select the file /neuro/dacq/setup/phantom.fif.

3. Digitize the HPI coil locations on the phantom. The cardinal points coincide with the HPI coils. Compare the digitized distances of the coils with the actual values to verify correct digitizer operation.

4. Put the phantom into the sensor helmet of the probe unit and push against the helmet. The front coil should point somewhat upwards. Connect the 32-pair cable between the phantom excitation multiplexer and the phan-

Table 2. Phantom data				
Fixed head position indicator coils				
Coil	**x [mm]**	**y [mm]**	**z [mm]**	**Dist. from center [mm]**
Right	79.5	0.0	0.0	79.5
Front	0.0	79.5	0.0	79.5
Left	-79.5	0.0	0.0	79.5
Back	0.0	-79.5	0.0	79.5
Dipoles (length = 5.0 mm)				
Dipole	**x [mm]**	**y [mm]**	**z [mm]**	**Dist. from center [mm]**
1	59.7	0.0	22.9	64.0
2	48.6	0.0	23.5	54.0
3	35.8	0.0	25.5	44.0
4	24.8	0.0	23.1	34.0
5	37.2	0.0	52.0	64.0
6	27.5	0.0	46.4	54.0
7	15.8	0.0	41.0	44.0
8	7.9	0.0	33.0	34.0
9	0.0	-59.7	22.9	64.0
10	0.0	-48.6	23.5	54.0
11	0.0	-35.8	25.5	44.0
12	0.0	-24.8	23.1	34.0
13	0.0	-37.2	52.0	64.0
14	0.0	-27.5	46.4	54.0
15	0.0	-15.8	41.0	44.0
16	0.0	-7.9	33.0	34.0
17	-46.1	0.0	44.4	64,0
18	-41.9	0.0	34.0	54,0
19	-38.3	0.0	21.6	44.0
20	-31.5	0.0	12.7	34.0
21	-13.9	0.0	62.4	64.0
22	-16.2	0.0	51.5	54.0
23	-20.0	0.0	39.1	44.0
24	-19.3	0.0	27.9	34.0
25	0.0	46.1	44.4	64.0
26	0.0	41.9	34.0	54.0
27	0.0	38.3	21.6	44.0
28	0.0	31.5	12.7	34.0
29	0.0	13.9	62.4	64.0
30	0.0	16.2	51.5	54.0
31	0.0	20.0	39.1	44.0
32	0.0	19.3	27.9	34.0

tom. Connect the separate HPI coil set connector of the phantom to the connector of the HPI cable connected to the HPI outlet underneath the side cover of the gantry.

5. Start the measurement. Do the head position measurement in the usual way as decribed in the *Data acquisition User's Manual.*

6. Start the phantom dipole control utility program by double clicking its icon in the "*MEG:Maintenance*" folder.

7. Activate dipole 1 by entering its number to the phantom dipole control dialog and click "Do it".

8. Check that the MEG signals (sine wave cycles) and triggers appear on the raw data display.

9. Activate "Average". Wait until the limit of 100 epochs is reached.

10. If you want to measure another dipole, advance the dipole number in the phantom dipole control dialog and click "Do it" again. When measuring many dipoles, it is advisable to reset the MEG channels between the dipoles (select "Tools/Reset channels"). Continue from step 8.

11. When all required phantom dipoles are measured, stop the measurement and save the file. This file contains the responses of all measured dipoles, stored as different categories.

12. Start the Source Modelling Program. Open the file saved at previous step and pick up one of the dipole categories. Set the sphere model origin to (0,0,0) in the head coordinate system, and set the baseline from –50 to 0 ms. You may want to select "accurate coil definition" from the DipoleFit/ Preferences menu. Fit single dipoles to the peaks of the response. For further instructions on how to fit the dipoles, refer to *Source Modelling Software User's Guide.*

13. Compare the localization results with the positions given in Table 2 and check that the amplitudes roughly match with the dipole moment selected at step 7 (due to the finite precision of the physical dipole length, the measured dipole moments typically differ slightly from the nominal value). Note that the Source modelling program displays the dipole moments (Q) as zero-to-peak values whereas phantom dipole select uses peak-to-peak values.

7.3 Voice intercom system (option)

7.3.1. General

The intercom system makes it possible to communicate with the subject between and during the measurements. It has been designed not to cause any interference to the Elekta Neuromag®. However, in order to avoid disturbances, the microphone should be kept further than 30 cm away from the helmet.

Figure 7.3 illustrates the system. It is composed of a table station (1) and main station with power supply (2). The microphone (3) of the main station is inside the magnetically shielded room. The microphone cable runs to the main station via the feedthrough filter. The loudspeaker for main station is outside of the magnetically shielded room attached on a separate feedthrough tube on the magnetically shielded room wall (4).

7.3.2. Usage

To open the connection to the magnetically shielded room, press "CALL 11" button on the table station. A short tone, a green light and number "11" on the display of the table station indicate that the connection is established. By default, the unit operates in automatic speech direction control. Note that the subject can hear what is spoken in the control room. It is also possible to switch the unit to simplex mode with manual speech direction control by pressing the "T" button. Then it is possible to listen to the subject, but the subject can't hear what is spoken in the control room. In order to give instructions to the subject, press "T"-button on the table station and speak close (≤50 cm) to the device. The button has to be kept down as long as you speak. During that time you can't hear what the subject says. When the button is released, the system returns to the "listening mode". To close the connection, press "X"-button.

To return to automatic speech direction control mode, close and re-open the connection by pressing "X" and "CALL 11".

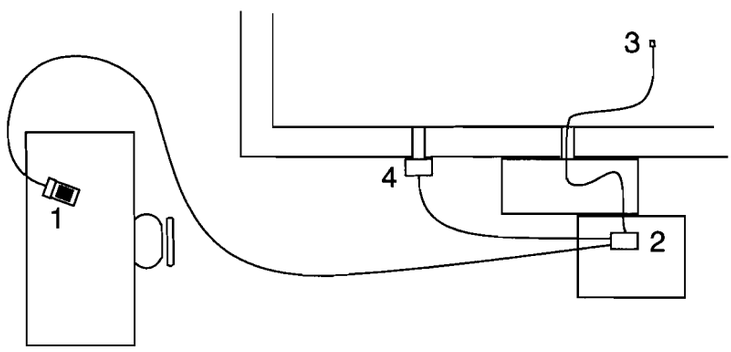


Figure 7.3.. The intercom system. For explanations, see chapter 7.2.1.

The volume of the loudspeaker to the magnetically shielded room is adjusted inside the main station. For more information, see the intercom instruction booklet.

7.4 Video monitoring system (option)

7.4.1. General

The schematic diagram of the closed-circuit television system is shown in Fig. 7.4. The camera (1) is placed inside a separate RF-shield. The cable (2) goes through a dedicated feedthrough to the monitor (3). The camera should be kept further than one meter away from the Elekta Neuromag® in order to avoid additional noise.

7.4.2. Usage

The system is activated by switching on the monitor unit and the power supply for the camera. It is possible to connect two cameras to the monitor unit. Anyhow, one must keep in mind that the cameras inside the MSR have to be provided with RF-protection housing. The MSR camera is connected to the input 1. It is selected by pressing the "camera 1" -button on the front panel of the monitor unit. For more information, see the CCTV instruction booklet.

7.5. Audio electronics

The connection of the audio electronics in the gantry side panel is shown in Fig. 1.20 of Section 1.10. The electronics has audio output connectors for the patient's and, optionally, for the assistant's non-magnetic earphones. The system also includes a microphone input connector and a microphone for the optional intercom unit.

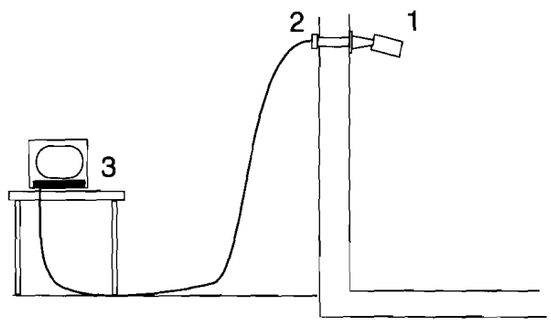
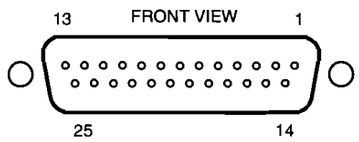


Figure 7.4. The video monitor system. For explanations, see text.

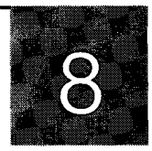
7.6. Analog input

Eightanalog inputs (standard, optionall 16 with the 128-channel EEG expansion) for miscellanaous analog signals (±10 V) are available in the main electronics cabinet. The inputs are connected to a parallel D25 multipole connectors (1 connector/8 channels) at the back of the main EEG rack. A fanout box for eight BNC connectors is also provided. The pinout for the parallel connectors is shown in Fig. 7.5.



1: Input 1	5: Input 5	14: Ground 1	18: Ground 5
2: Input 2	6: Input 6	15: Ground 2	19: Ground 6
3: Input 3	7: Input 7	16: Ground 3	20: Ground 7
4: Input 4	8: Input 8	17: Ground 4	21: Ground 8

Figure 7.5. Analog input connector pinout



8. Maintenance

8.1. Maintenance program

The following maintenance program is recommended:

- Before every measurement: check artefacts and noise (check made by user)
- Every morning: check Helium level, check MEG noise by recording signals without subject, determine need for tuning, tune if necessary (made by user). For EEG channels, connect the signal terminators to the electrode panel and verify the operation by using the internal test oscillator (test made by user).
- After every EEG measurement: cleaning of electrodes and electrode caps, check for wear (made by user)
- According to a site-specific user-derived schedule, typically about once a week: liquid Helium refill (made by user). A fixed weekly schedule is recommended
- Regular: phantom measurements, daily or at least once a week, are recommended (made by user). See section 7.2.
- Once every year: annual maintenance service (made by authorized service personnel)

8.2. Checkup before every measurement

Before each measurement session, it is advisable to set up the measurement fully and make at least part of the measurement first with empty room, then with possible stimulators connected but with no subject, and finally with the subject in the measurement position. Check visually both in EEG and MEG channels for

- Stimulus artefacts
- Line interference
- Noise
- Bad channels
- Stimuli coming (if used)

The "responses" in an empty room measurement should be virtually flat lines showing only normal average noise. If you encounter a problem, try

to remove the problem by simplifying the setup as long the problem has been identified. Especially try to determine which issues have changed since the system last time operated without trouble.

NOTE! Excessive noise on the channels may deteriorate signal quality and lead to incorrect measurement. Usually, a few noisy channels does not, however, cause problems as this can be taken into account by rejection settings in data acquisition in the in source localization (refer to corresponding software manuals).

8.3. Noise level follow-up and MEG channel tuning

Every day, preferably in the morning, the noise level of all channels should be checked by making an empty-room measurement. Bad channels, if any, are tuned according to *Sensor Tuner User's guide.*

Let Autotuner-program run always when appropriate. See *Sensor Tuner User's guide.* It is recommended to save a good basic setup (having low overall noise) which is always used as the starting point for the autotuner program.

8.4. EEG channel checking

To check the noise level of EEG channels, connect the signal termination blocks (1-MΩ resistance to isolated signal ground for each amplifier input) to the electrode interface panel 37-pin connectors. Do a measurement with EEG channels switched on. Select the EEG channel sets in the raw data display. and verify that there are no channels whose noise level clearly exceeds that of other channels or shows a completely flat line.

For further checking of the EEG channels, use the Squiddler-EEG utility program which can be invoked from the Tools menu of the Acquisition control program. The control dialog is shown in Fig. 8.1. The parameters are explained below:

Per-channel parameters:

- Active: Selected preamplifier (or all preamplifiers) on/off. Set to Off
- Gain: Select 5000 / 500 / 150 (nominal gain,actual value taken into account via the calibration coefficient. Value in parenthesis indicates maximum peak-to-peak signal to electrode input. Normally 5000 for unipolar EEG channels, 500 or 150 for bipolar channels (EOG, EMG, etc.). Set 5000 for channels 1–60, and 500 or 150 for EEG61–EEG64, depending on software configuration. Nothing is shown in the ALL mode.
- HPF: Hardware high-pass filter -3 dB corner frequency. Set to 0.1 Hz

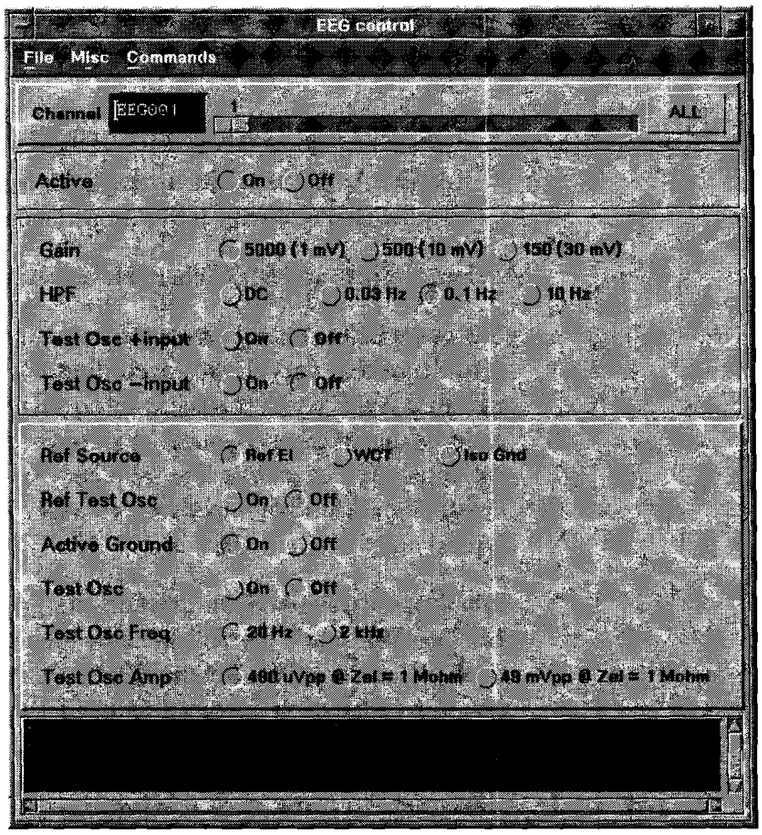

EEG control
File Misc Commands
Channel EEG00 1
1
ALL
Active On Off
Gain 5000 (1 mV) 500 (10 mV) 150 (30 mV)
HPF DC 0.03 Hz 0.1 Hz 10 Hz
Test Osc +input On Off
Test Osc –input On Off
Ref Source Ref El WCT Iso Gnd
Ref Test Osc On Off
Active Ground On Off
Test Osc On Off
Test Osc Freq 20 Hz 2 kHz
Test Osc Amp 480 uVpp @ Zel = 1 Mohm 48 mVpp @ Zel = 1 Mohm

Fig.8.1. Example of the "Squiddler-EEG" utility program user interface.

- Test Osc +input: Connect the internal test oscillator + signal to the + input of this channel. Used both for bipolar and unipolar channels. "Test Osc" must also be on (see below) to use the test signal. Set to Off.
- Test Osc –input: Connect the internal test oscillator – signal to the – input of this channel. Used for bipolar channels together with "Test Osc + input". Leave off when testing unipolar channels. "Test Osc" must be also on (see below) to use the test signal. Set to Off.

Common parameters:

- Ref Source: Select reference electrode, Wilson Central Terminal (WCT, computed average of unipolar channels 1–3) or isolated signal ground of the preamplifiers. Set to "Reference electrode" (normally used). See Appendix for explanation of terms.
- Ref Test Osc: Connect test oscillator signal to reference electrode input. "Test Osc" must also be on (see below) to use the test signal. Set to Off.
- Active ground: Connect AC signal from reference electrode to isolated signal ground driver. Set to Off.

- Test Osc: Test oscillator on/off. To use the test signal, the connection to individual channel inputs (see above) must also be enabled. Set to Off
- Test Osc Freq: Test oscillator frequency. Set to 20 Hz
- Test Osc Amp: Test oscillator amplitude (nominal value at input assuming terminator block with 1-MΩ impedance connected).

Select all EEG and MEG channels and start acquisition (hit GO).

Select the EEG channel sets in the raw data display. Set the EEG scale to 20 μV (this may vary slightly according to local line noise level). Observe the noise level. Verify that there are no channels whose noise level clearly exceeds that of other channels or shows a completely flat line. Note that the apparently excessive line frequency interference seen in this step is due to high electrode impedance (1-MΩ); in actual measurements with typical electrode impedances of 5–10 kΩ it will be much smaller.

Enable the test signals from the built-in signal generator; in the Squiddler-EEG control, click the ALL button, then click "Test Osc +input" and finally "Test Osc On". Set the EEG scale of the raw data display to 300 μV. Verify that there is a clean sinusoidal wave of equal amplitude on all EEG channels. Every other channel should be 180 degrees out of phase (the test signal feed is inverted, not the input). The amplitude of the differential channels can be different from that of the single-ended channels.

If necessary, record a short period of test signal and verify that amplitude is same for all channels using e.g. the signal processor program. Note that the internal test oscillator is intended only for routine qualitative calibration checking, accurate calibration is performed according to calibration procedure EL20868Y, carried out by an authorized service engineer.

8.5. Troubleshooting

Try to remove the problem by simplifying the setup until the problem has been identified. Especially try to determine **which issues have changed** since the last time the system operated without a trouble. Possible, quite common causes of artefacts, noisy and flat channels are, e.g.,

- Improper grounding of stimulators or other peripherals, causing currents to flow in the walls of the magnetic shield (stimulus artefacts, line interference, computer data transfer artefacts). → Check that grounding is single-point. Consult Elekta Neuromag's representative if in doubt how to connect the equipment.
- Multiple grounding points because of improperly added equipment (line interference). → Check that grounding is from a single point only.

- RF interference from external sources caused by extra unfiltered cables drawn into the magnetically shielded room (increased noise, level shifts). → Check all the leads inside the magnetically shielded room. Check that the cables are RF-filtered properly.
- Active digital equipment in stimulus cabinet, inducing interference to leads going inside the MSR. → Shield the digital device or, preferably have it outside the stimulus cabinet and feed the signals through a feedthrough filter
- Stimulus cables improperly connected (stimuli not coming, artefacts, line interference or RF interference). → Check cabling.
- Incorrect tuning (noise, some channels saturated). → Tune.
- Too low liquid Helium level (noisy channels, saturated channels). → Transfer Helium
- Magnetic contamination on the subject (big artefacts). Remove subject and check with empty room. → Check subject and try to demagnetize.
- In the worst case magnetic objects near the sensor array lead to trapping of flux in the sensors, causing flat or noisy channels which are not recovered by taking the subject out. → Detrapping using the sensor heaters is needed (see Section 2.4.2).
- Loose EEG electrode or bad connection to skin → Check connection. Clean skin and re-attach electrode
- Bad EEG cable connections → Check electrode cap or headbox cable connections.
- Reference or active ground electrodes badly connected or left open → Check connection.
- Unused EEG channel left active → Unused channels should be switched off from data acquisition, see Chapter 8.4.
- Data acquisition lock-up (e.g. red fail lights on main electronics boards, stops responding, connection lost) → reset, see Chapter 6.6.

8.6. Monitoring the liquid Helium level

As part of the standard maintenance, the Helium level should be checked regularly. There are three differenent ways to accomplish this:

- Push the toggle switch of the local display inside the shielded room to turn the display on and wait for 20–30 seconds for the display to stabilize. Remember to switch the display off by pushing the toggle switch again
- Select "*Helium*" from the "*Tools*" menu of the data acquisition program

- Double-click the icon of the "*Helium*" utility from the "*Maintenance*" folder

The level is automatically recorded in computer's memory, and the current level and recent history can be read from the computer screen using the separate "*Helium*" utility. The boiloff rate should also be occasionally checked. A substantial increase of the boiloff rate usually signifies need for service (regenerating the vacuum which must be left for trained service personnel).

When the liquid Helium level has reached near or to 0%, new liquid must be transferred. A regular weekly transfer schedule is recommended.

NOTE! Do not leave the system warm up by itself.

Usually, however, after the level has reached 0% it takes approximately one day before all the liquid is evaporated from the system. Carrying out measurements during this period is possible but disturbances due to low level of Helium may occur. It is good practice to ensure beforehand that replacement liquid Helium is available when needed by having a spare storage container always at hand or at least having a second, independent supplier of liquid.

See section 4.4 for Helium transfer instructions.

8.7. Cleaning

The HPI coils and the painted parts of the Elekta Neuromag® system and the HPI coils can be cleaned and disinfected with pure alcohol.

The upholstering of the patient's bed and chair, and the wooden digitization chair are cleaned with soap water or ordinary mild dish care detergent.

Immediately after each measurement session, soak the electrode cap with electrodes in place and single electrodes in plain water for 20 minutes so that most of the paste is disolved into the water. The rest of the paste is washed away with a hand-held shower. A soft small brush can also be used. Use ordinary soap or mild dish care detergent such as Fairy™ if necessary to clean the residue. Be careful not to let water into the D37 connectors. Allow to dry. Pure alcohol can be used for disinfection. Do not leave old paste to harden in the electrode cavity as it may be difficult to remove later.

The white cover of the phantom can be cleaned with with soap water or ordinary mild dish care detergent.

The computers and their displays included in the system must be cleaned with agents and wipes specifically designed for this purpose. Do not spill liquids inside the keyboards or other devices where they can cause short-circuits and damage to the devices.

Note! When cleaning the gantry, especially the interior of the helmet (= outer surface of the helmet), observe that risk of flux trapping to sensors exists, resulting in artefacts. Therefore, magnetic objects like wristwatches, belt buckles, magnetic buttons on sleeves etc. must not be brought in the vicinity of the Dewar. Refer to chapter 2.4.

8.8. Coating of Ag/AgCl electrodes

The sintered Ag/AgCl electrodes such as used in the Elekta Neuromag EEG cap do not need chloriding.

To coat solid-metal Ag/AgCl electrodes, immerse the single electrodes and the electrode cap with electrodes in place into a saline (NaCl) solution. Use about one tablespoon of NaCl per one liter of water. Draw a 10-mA constant current through each electrode simultaneously using a graphite cathode connected to the negative terminal of a power supply and the electrode leads connected to the positive terminal. A good Ag/AgCl coating is usually formed in about 5 minutes. Rinse the electrodes thoroughly in water.

8.9. Annual maintenance

The annual maintenance service must be left for trained service personnel. The service includes:

- Overall system performance test (noise, phantom measurement)
- Identifying causes of unresolved reported problems
- Checking of magnetically shielded room (grounding, installations, door mechanisms etc.)
- Checking and cleaning of the Dewar (boiloff rate)
- Re-evacuating the Dewar vacuum if necessary
- Performing detrapping if necessary
- Checking of siphons, re-evacuating if necessary
- Checking the mechanisms of the gantry, including the rope, replacing worn-out parts, lubricating mechanisms if necessary and cleaning the unit. The ropes are changed every five years.
- Checking the bed and chair mechanisms and cleaning both of them, top up of the hydraulic liquid of the chair and inspection for leaks

- Checking the feedthrough filter unit, the electronics cabinet, and the data acquisition system cabinet, including checking all cabling and replacement of dust filters if necessary
- Checking of grounding and isolation arrangements
- Cleaning
- Checking workstations and peripherals, including checking software versions
- Checking liquid Helium gauge
- Checking and changing defective and worn-out parts
- Checking intercom and video monitor operation (if installed)
- Checking the accessories
- Tuning of the system
- Overall system performance test (noise and phantom measurement, calibration) after the service

A

Appendix

Basic concepts, terminology

A/D conversion

Conversion of an analog signal to digital form, digitalization.

Anti-aliasing filter

A low-pass filter designed to limit the signal bandwidth to less than half of the sampling frequency. If the signal being digitized contains frequency components higher than half of the sampling frequency, a phenomenom known as aliasing occurs, whereby higher frequency components are folded back to lower frequencies, introducing spurious signal components.

Applied part

Parts of the system in direct contact with the person being investigated with the system.

BF type

Body floating. An applied part providing enhanced protection against electrical shock. An applied part of BF type must fulfill leakage current requirements specified in the standard IEC 60601-1 even in the case that the patient is unintentionally connected to an external mains voltage.

Cryopumping

Adsorption of gases on surfaces on cryogenic temperatures. See detailed description in Section 2.1.

Class I device

A device whose protection agains electrical shock does not rely only on basic insulation but also has a permanently connected protective earth connection so that accessible metal parts cannot become live if basic insulation is damaged.

D/A conversion

Conversion of a digital signal into analog form.

Dewar

A thermally insulated vessel for cryogenic liquids. It has a vacuum-insulated double-wall structure. The vacuum space also houses thermal radiation shields.

Feedback loop, Flux locked loop

A readout method for the SQUID sensor where the output of the preamplifier is fed magnetically back to the sensor. In this configuration, the sensor acts as a null-detector while the feedback effectively compensates for the input magnetic field. The feedback signal is thus equal to the input magnetic field; a copy of the feedback signal is then used as the output. Flux locked loop provides a linear input-output relation whose calibration is to a large amount independent of individual component gain variations.

Flux transformer

A superconducting circuit comprising at least two coils connected in series. Because of superconductivity, magnetic flux is conserved. Thus, a magnetic field imposed on one of the coils will induce a shielding current to flow in the circuit, cancelling the effect of externally imposed flux. Since the shielding current will induce a magnetic field in other coils belonging to the circuit, a flux transformer can be used to scale magnetic field intensity by varying the coil parameters.

EEG active ground

See EEG Ground terminal.

EEG bipolar channels (Differential channels)

Channels with terminals for both the positive (+) and negative (-) amplifier inputs separately for each channel. The reference is irrelevant for differential channels. EEG channels 61 ... 64 are differential in the standard configuration.

EEG ground terminal, Active ground

A terminal for attaching an electrode to equalize the potential of the subject with respect to the preamplifier signal ground. As described above, the pre-amp unit is floating. Thus, there has to be a way to set it to a common potential with the subject in order to keep the input amplifier at linear operating range over extended periods of time and to minimize the common mode voltage between the subject and the amplifier.

Traditionally, this has been accomplished by connecting the isolated preamplifier signal ground directly to the subject with an EEG electrode. However, there are drawbacks with this approach; in a fault condition, the

maximum patient leak current allowed by patient safety regulations may be exceeded and the amount of common-mode interference is affected by changes in the impedance of the reference electrode.

To work around this, the subject is connected to isolated preamplifier signal signal ground by means of a current-limited amplifier (driver) that even in a fault condition keeps the current of the ground electrode within acceptable limits. In addition, the ground driver can also be actively controlled so that the ac signal components (above approximately 5 Hz) seen on the reference electrode input are compensated for by the active ground driver. Consequently, the potential difference between the patient and isolated preamplifier signal ground is smaller than without the active grounding circuit, and results in a better common-mode interference rejection. Another way to understand the operation of the circuit is that active ground reduces the impedance of the ground electrode by a factor of 10.

The ac signal from the reference electrode to the active ground driver can be switched on and off by using the "Squiddler-EEG" utility program. When in off position, the input of the ground driver is connected to isolated preamplifier signal ground.

The active ground driver socket on the gantry side panel and headbox is labelled "GND" as is customary in the EEG practice although the term strictly speaking refers to isolated preamplifier signal ground potential. Ground electrode should always be connected to the terminal labelled "GND" on the side panel or headbox when making measurements.

EEG isolated preamplifier signal ground (GNDi)

Ground potential (signal zero-level) of the EEG preamplifier system. As patient safety regulations require, this ground is isolated from all other grounds in the system, including the shielded room. Thus, the EEG preamplifier unit is floating.

Internally, the preamplifiers see all signals with respect to GNDi. Technically speaking, isolated ground refers to the center tap of the secondary of the safety isolating transformer of the EEG preamplifiers.

Because of safety principles, isolated ground should never be connected directly to humans (see below). In the headbox and electrode caps supplied with the system or available as options, isolated ground is not accessible.

EEG reference

Signal subtracted from all the single-ended channels. In normal EEG measurements, the reference signal is derived from the reference electrode. For ECG measurements, the Wilson Central Terminal (WCT, see below) reference can be used. For testing and calibrating the EEG system,

the reference signal can be connected to the isolated ground of the preamplifiers. The source of the reference signal can be selected by using the "Squiddler-EEG" utility program.

EEG reference electrode

An electrode, placed usually at an inactive area, monitoring the potential of the subject. This can serve for two purposes, depending on the mode of the preamplifier: 1) it gives the signal ('reference') which is subtracted from the single-ended EEG channels when selected as the reference source, and 2) it acts as a sensor for the active ground driver. Because of 2), the reference electrode has to be connected even when using only differential EEG channels with the active ground switched on.

EEG unipolar channels (Single-ended channels)

Channels with just one electrode per channel (+), and sharing a common reference signal (-). The reference signal can come from various sources, see EEG reference. EEG channels 1 ... 60 are all single-ended.

EEG Wilson central terminal (WCT)

Average of limb electrode potentials. When Wilson central terminal is selected as reference, the average of the signals of the channels EEG1–EEG3 is subtracted from all the single-ended channels. This mode is used only in some ECG measurements when electrodes EEG1–EEG3 are attached to limbs.

Gradiometer

A flux transformer coupling external magnetic signal to the SQUID detector, making the SQUID to respond to spatial variations of the external magnetic field. A gradiometer comprises a multiple pickup coil and a signal coil which couples the signal to the SQUID. The gradiometer is insensitive to uniform magnetic fields.

IEC60601

A family of international standards concerning the safety of medical electrical equipment and systems

Leakage current

Current that is not functional. For example, patient leakage current is the unintentional current that flows from equipment via patient to ground

Magnetically shielded room (MSR)

A special enclosure whose walls, floor, and ceiling made of plates of high-permeability alloy and of high-conductivity metal (typically Aluminium). Typically, the magnetically shielded room has 2-3 such concentric shells, separated by a few hundred mm. The room distorts the

external magnetic field in such a way that the magnetic field inside is substantially weaker. The shielding efficacy increases with frequency.

Magnetometer

A flux transformer coupling external magnetic signal to the SQUID detector, making the SQUID to respond to the external magnetic field. A magnetometer comprises a single pickup coil and a signal coil coupling the signal to the SQUID.

Planar gradiometer

A gradiometer where the mutliple pickup coil is made of two adjacent loops. The planar gradiometer is sensitive to spatial changes of the magnetic fields in a direction along the line joining the centerpoints of the lines. A planar gradiometer has a focused, directional sensitivity pattern and couples strongly to currents right underneath it.

Siphon

A vacuum-insulated tube for transferring liquid Helium from storage vessel to the probe unit. The Elekta Neuromag® transfer siphon comprises a flexible part and a fixed part.

SQUID

Superconducting QUantum Interference Device: The SQUID is an ultrasensitive magnetic flux detector based on superconductivity and so-called Josephson effect. It operates at cryogenic temperatures.

Superconductivity

A state where electric resistance equals zero. Present in several substances, e.g. in Niobium and Lead. A superconductor also repels magnetic flux, i.e., magnetic field lines cannot penetrate the superconductor.

Trapped flux

A phenomenom where magnetic flux is trapped in supreconducting structures, e.g., thin films. A superconductor normally repels magnetic flux. However, if regions of the superconcutor become non-superconducting as a result of being exposed to strong magnetic fields, magnetic field lines can enter the superconductor and become trapped inside superconducting areas. May lead to deteriorated operation and increased noise of the SQUID sensor. Movements of the trapped flux are seen as magnetic signal jumps. Trapped flux can be released by heating the superconductor above its superconducting transition temperature, typically over 10 K.

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